DETERIORATION
OF STRUCTURES IN
SEA-WATER
FIRST REPORT OF THE
COMMITTEE OF THE INST. C.E.

1920

COMMITTEE

OF

THE INSTITUTION OF CIVIL ENGINEERS

APPOINTED TO INVESTIGATE

THE DETERIORATION OF STRUCTURES OF TIMBER, METAL AND CONCRETE EXPOSED TO THE ACTION OF SEA-WATER

FIRST REPORT OF THE COMMITTEE

EDITED BY

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THE DETERIORATION OF STRUCTURES OF TIMBER, METAL AND CONCRETE IN SEA-WATER.

INTRODUCTION.

In July, 1916, the Council of The Institution of Civil Engineers applied to the Advisory Council of the Committee of the Privy Council for Scientific and Industrial Research to obtain a grant in aid of a research, under the direction of The Institution, into the deterioration of structures of timber, metal, and concrete, when exposed to the action of sea-water in various localities, and as to measures for the preservation of such structures. It was proposed that investigations should be carried out on the initiative of the Council of the Institution, or of a Committee to be appointed by them, and that the main experimental work should be conducted at the principal ports in the United Kingdom, India, the Dominions, and Colonies. Some forty ports were accordingly selected in the first instance, as affording suitable conditions for the prosecution of the research, and the chief engineers of these ports, who were members of The Institution, signified their willingness to perform the necessary duties.

As the research entailed the investigation of phenomena, the action of which is not rapid, it was pointed out that the experimental work would occupy a long period of time, and that the results would not be fully known until the experiments contemplated by the Committee had been considerably advanced.

The Institution proposed that, subject to the approval of the Advisory Council, a Special Committee should be appointed, and undertook to provide the necessary accommodation for that Committee's labours.

The Special Committee nominated by The Institution for carrying out the research was constituted as follows:—

Sir William Matthews, K.C.M.G. (*Chairman*),
Sir John A. F. Aspinall, M.Eng.,
Sir John Wolfe Barry (since deceased),
Sir R. Elliott-Cooper, K.C.B.,
Sir Archibald Denny, Bart.,
Sir John P. Griffith, M.A.I.,
Sir Robert Hadfield, Bart.,
Mr. A. G. Lyster, M.Eng.,
Mr. B. Mott, C.B.,
Mr. F. Palmer, C.I.E.,
Mr. A. Ross,
Sir T. Sims, C.B.,
Mr. W. B. Worthington, B.Sc.

The following members were subsequently co-opted :—

Mr. C. S. Meik,
Mr. M. F. G. Wilson,
Mr. E. F. C. Trench, M.A.,
Mr. G. W. Humphreys,

the Secretary being Mr. P. M. Crosthwaite, B.A.I.

On the 11th August, 1916, the Secretary of The Institution was informed that, on the recommendation of the Advisory Council, now constituted the Department of Scientific and Industrial Research, the Committee of the Privy Council were prepared to make a grant in aid towards the cost of the research, subject to certain conditions, a memorandum of which was enclosed, and which, *inter alia*, approved of the constitution of the proposed Committee and its *personnel*.

After consideration by the Council of The Institution these terms were agreed to, and the Special Committee of The Institution commenced the collection of the necessary information in October, 1916.

Owing to difficulties in obtaining materials and skilled assistants during the War, it was found necessary to defer many of the contemplated experiments for the time being, and to confine the Committee's work for the present time mainly to investigations dealing with Existing Structures.

With a view to obtaining such information the Committee, in November, 1916, issued instructions to the Port Engineers, who were appointed corresponding members, setting out the character of the information required, and asking for reports on the structures under their charge. In reply to this request the Committee have been furnished with reports on structures, in some cases accompanied by explanatory drawings and photographs, by the following Engineers and others :—

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The Committee have now decided, with the consent of the Advisory Council, to issue a first volume of their Proceedings dealing with Existing Structures, the materials used in their construction, together with the deterioration thereof, and to publish in connection therewith a number of the above-mentioned Reports. Owing to lack of space it has unfortunately been impossible to print *in extenso* all the Reports received, and in some instances abstracts only have been given. The original Reports are, however, preserved at the Museum of the Institution of Civil Engineers for reference.

In order to place on record the work done in former years, and to furnish a general outline of the opinions of the engineering profession on this subject, down to the present time, Mr. G. R. Redgrave, Assoc. Inst. C.E., was directed by the Committee to prepare a brief digest of the contents of Papers already published in the Minutes of Proceedings of the Institution of Civil Engineers relating to the action of sea-water on structural

materials. This is arranged in such a way as to indicate the chief matters cognate to the investigations of the Committee, under the general headings of "Timber," "Concrete" and "Metal Work." It was, moreover, decided that this Digest or Report by Mr. Redgrave should take the form of a preliminary chapter, giving references to the different Papers consulted, but treated in such a manner as to interest the general reader and to serve as a suitable introduction to the more formal and technical Papers that were to follow.

In dealing with the purely scientific aspects of the question, the aid of special experts has been invoked in order to prepare reports on certain of the chief subjects of enquiry. Thus Mr. FitzSimons, B.Sc., Assoc. M.Inst.C.E., has treated of timber from the point of view of construction, incorporating additional botanical observations and notes by Mr. F. T. Brooks, M.A. Dr. Calman has contributed an account of the various organisms found to be harmful to timber in the sea, and Dr. Newton Friend has dealt with the injuries caused to metal work by exposure to sea-water. These reports may be regarded as representative of the scientific opinion which prevails on the matters enquired into by the Committee, and it is thought that they furnish information in a form likely to be useful to the Engineer.

For the sake of convenience in arranging the large mass of documents already received by the Committee, it has been decided to keep the reports from the different parts of the United Kingdom separate from the Colonial reports. In each case the Papers are printed in alphabetical order, and the work of the Colonies and Dependencies has been subdivided into six main groups—Africa, Australia, New Zealand, India and the Middle East, China and the Far East and America. By grouping the reports in this way it becomes possible to keep the cognate documents together and to arrange the work in a manner handy for the purpose of reference.

The task of editing and preparing these reports for publication, under the direction of the Committee, has been entrusted to Mr. Redgrave, who has carried out the duties which devolved upon him in a very satisfactory manner, not only with regard to the editing of the Papers, but also with respect to the arrangements in connection with the reproduction of the plans and photographs, and in many other matters relating to the recording of the Committee's proceedings.

Several of the reports above referred to were accompanied, as already stated, by detailed drawings of the structures described, together with photographs, and specimens of materials that have been exposed for several years in sea-water. These plans, photographs, and specimens are preserved in a room set apart for the purpose in the Institution building, and may be conveniently examined when desired. It is intended that they should form the nucleus of a museum to illustrate the whole subject of the Committee's research.

As it will not be possible to obtain sufficient information for some time concerning many of the subjects for which further investigations are needed, and respecting which arrangements are being made, or where protracted observations have been set on foot, it is hoped to publish the results of these further investigations in a subsequent volume.

ABSTRACT

OF REFERENCES IN THE PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS TO THE DETERIORATION OF STRUCTURES AND MATERIALS THROUGH SEA-ACTION.

By GILBERT R. REDGRAVE, Assoc. Inst. C.E.

I. TIMBER.

Wood was no doubt the first material to be used for structural purposes in sea-water, and in its various forms, as employed for boat-building and for the construction of piers, jetties, and harbour works, its use reaches back to the very earliest times. At a somewhat later date, many structures of masonry were built in the sea, or in close proximity to it, and during a much more recent period, iron, both cast and wrought, and steel, as also concrete, have come to be extensively employed for such structures.

It will be convenient, in giving an account of previous investigations into the subject of the deterioration of structures exposed to sea action, to consider the various materials, in the order of their original employment, and to discuss, in the first place, the references made by earlier writers to the decay and destruction of timber. Many of those who have dealt with this matter have alluded to the great antiquity of the depredations of the *Teredo navalis*, commonly known as the "Ship-worm," as this scourge is spoken of by Pliny and Ovid, some 1,900 years ago, and it is also said to be mentioned by Homer, but, long before the earliest traces of civilization, teredines caused serious injuries to timber, and specimens of fossil wood pierced with their boreholes have been found in many parts of the world. In Roman times, ships in the Mediterranean were sheathed with metal for protective purposes, and we read concerning vessels sent on a voyage of discovery in the reign of Henry VI:—"They cover a piece of the keeles of the shippe with thin sheets of leade, for they had heard that, in certain partes of the ocean, a kind of wormes is bredde which many times pearceth and eateth through the strongest oake that is."

Several kinds of ship-worms, which are really molluscs of the genera *Xylotrya*, *Nausitora* and *Teredo*, are found in different parts of the world,

and they abound in the warm seas of the Tropics, though they will live and flourish in waters in the Temperate Zone, especially if they are warmed by the gulf-stream.

The activity of many of these worms appears to depend largely upon the density of the water, and consequently on the percentage of salt present. The teredo will not flourish in brackish water, nor in sea-water much diluted with fresh water. Sewage matter seems to be speedily fatal to it, and it cannot continue to thrive in muddy and turbid waters. Thus it is said to be absent in the Inner New York Harbour, though abundant in the Ocean outside. It rarely works at a greater depth than 30 feet, and confines its ravages from about half-tide level down to the sea-bottom. It will penetrate into most kinds of timber, though it attacks more readily soft wood such as fir and pine. Oak and other hardwoods are also liable to be injured by the teredo, but the "worm" does not then grow so freely, nor attain so large a size, hence the destruction is less rapid.

In addition to the depredations of the ship-worm, known in Australia as the "cobra," certain small crustaceans, including the "sea-louse," *Limnoria lignorum*, sometimes known as the "boring gribble," together with the *Chelura* and *Sphæroma*, are very destructive to timber in sea-water.

Much has been written concerning the life-history of the teredo, and an excellent account of this mollusc is contained in an Article by Dr. E. H. von Baumhauer, the Dutch Commissioner to the Exhibition of 1878, printed in the *Popular Science Monthly* for August and September, 1878. Illustrations are given to explain the means employed by the teredo to bore out its galleries in the timber, and to describe the muscular action involved in the work. The living teredos were found of both sexes, the females were much more numerous than the males, in the proportion of twenty to one. The females are oviparous and the eggs are expelled from one of the pair of branchial siphons, with which the mollusc is provided. The mode of impregnation is unknown, but M. de Quatrefages, the eminent French naturalist, investigated the metamorphoses which the eggs undergo from the time they leave the body of the parent until the fully-formed larvæ attach themselves to the surface of the timber, and begin to bore on their own account. The young teredo is provided with vibratile cilia, by means of which it moves freely in the water, and at the end of the fourth day it passes out of the embryonic or larval stage, fully equipped for boring in wood, that is to say, the bivalve shell is formed, the foot appears on the outside, and the organs of motion in the water, the cilia, form a sort of crown. Like many other minute animalculæ, the young teredo can travel freely through the water by the action of the cilia, but, as soon as the foot appears, it can creep as well as swim, and can move on the surface of the timber, to which it attaches itself.

The eggs are produced in prodigious numbers, and the Xylotrya, a genus allied to the Teredo, is said to yield 100 millions of ova in the season from a single individual. Though it soon becomes sufficiently developed to attack timber, the young teredo may, it is believed swim

around in the sea-water for a month or more in search of a suitable habitat. It enters the timber horizontally, by means of a very minute pinhole, and the boring speedily becomes larger as the mollusc increases in size and works its way further into the wood, It follows the direction of the grain and passes upwards by preference. The burrow is lined by a nacreous substance, secreted by the teredo, which varies in thickness according to the nature of the timber, being much thicker and stronger in soft wood than in hard, and this lining serves to consolidate the tunnel. The tube is generally rather larger in diameter than the mollusc, but the teredo has the power of inflating itself to the full size of the lining.

In warm seas the teredo will in some cases attain an enormous size, and lengths of 4 and even 6 feet have been recorded, with diameters exceeding half an inch. Like other species of marine molluscs, the teredo feeds upon the infusoria and diatoms present in the sea-water, which is passed through its body in a continuous stream, by means of the siphon-tube at the lower end. This tube is always extruded through the opening by which an entrance into the timber was gained, but it is withdrawn when the teredo is alarmed or disturbed. Some observers, who have found the wood-pulp in the intestines, have concluded that the teredo depends to some extent upon this substance for its nourishment, but it is now generally understood that the mollusc merely bores into the timber for safety and shelter, and passes the minute particles of wood through its body, to remove them from its borehole in the most rapid and convenient way.

Very varying opinions have at different times been expressed concerning the manner in which the teredo contrives to bore its tunnels, even through the hardest wood. Some have thought that it was able to emit an acid secretion, which served to soften and break down the wood-cells, while others have asserted that the cutting away of the timber was due to the action of spicules of hard siliceous matter, in the nature of teeth, embedded in the gelatinous tissue of the mollusc. There is, however, no doubt that the timber is cut away solely by means of the shells, which are furnished with minute teeth, capable of filing away the wood. The animal has also some very powerful muscles, which serve to force the double shell against the end of its burrow, and to move it with a species of rotary action. The cutting edges on the shells are arranged in two directions at right angles to each other, which tends to prevent fouling, and the action in attacking the wood is rather that of a file than of an auger. This is well brought out by a study of the muscular system of the teredo. He does not bore out his galleries, but he rasps them away by the rotary motion of his shell. Having inflated his body with water, so as to fill out the pearly lining of his tunnel, and give him a firm purchase, he files away the wood in front of him by rapid motions imparted to the two valves of the shell, and the thousands of cutting teeth remove the material in very fine particles. It would seem to be the largest and last-formed teeth which do the actual work, and several observers have stated that by placing the ear against the pile in which ship-worms are burrowing, the rasping noise thus made can be plainly heard.

The sense of touch in the teredo is implanted in the suction disk. The foot, when extended, begins work by feeling the place before attaching itself to the spot and drawing its shell after it. Naturally, it avoids the places which seem to offer undue resistance, and it will turn aside at a knot or an iron bolt, and go round the obstacle. It would almost seem as if the sense of touch carried with it, in the case of the teredo, a delicate sense of hearing, for the worm never breaks through the thin shell which separates him from the gallery pierced by a comrade, and though a pile is riddled with tunnels, each boring is entirely distinct.

The teredo is furnished, as already stated, with two siphons, one being shorter than the other. The wood excavated in forming the tunnel passes through the intestinal canal, where it has been found from time to time on dissecting the mollusc, and it is expelled as a very fine whitish substance, which shows little trace of having been digested, or as having served for the nourishment of the teredo. As the mollusc is constantly drawing water through its body, by the action of the longer siphon, it requires for its respiration a clear and pure water, and it is probably for this reason that piles driven where sewage and turbid water are present are free from ship worms. It has been thought that the sulphuretted hydrogen of the sewage water proved destructive in these cases. If removed from its tunnel and placed in sea-water, the teredo generally dies in about 24 hours, and if the wood containing the worm is taken out of the sea the same result speedily follows.

The nacreous lining of the tunnel, containing about 97 per cent. of carbonate of lime, is secreted by the mantle of the teredo and is formed in rings, added to at regular intervals, as the mollusc increases in size. Between this calcareous casing and the body of the teredo a sufficient space is left to prevent any inconvenience in the act of respiration. It seems probable that when the mollusc becomes filled with water for this purpose his body is distended to occupy entirely the case or tube-lining. This pearly substance, when first secreted, is soft and flexible and of slight consistency, but it solidifies later and completely fits into all the irregularities in the wood. The cavity, when examined with a magnifying-glass, shows plainly the marks of the teeth on the shell, which file away the wood in minute grooves or rings.

Few of those who have written concerning the teredo have noticed the fact that he is not always allowed to possess his tube in peace and safety, but that he is pursued and preyed upon by a voracious annelid, to which De Hoan has given the name of *Lycoris fucata*. This creature has rather the look of a large centipede, and having once entered the tunnel of the living teredo he proceeds to devour his host at leisure. The Lycoris is furnished with rows of small feet on either side, and he has on his head a pair of horny jaws. These are strong and sharp and the upper ones are bent backwards in the form of tusks, with which he grasps his prey.

In some parts of the world much protection is afforded to timber, as also to iron and steel placed in sea-water, by barnacles and other creatures which attach themselves to the surface and cover it in deep layers, and the surface of the timber may be so overlaid by them that no opportunity

is given to the young teredines to gain a foothold. In some places large colonies of the sea-thorn, *Balanus sulcatus*, may cover the exterior of the wood so completely that their shells touch and baffle the intruding teredo.

It has been noticed that, in certain years, the attacks upon timber by the teredo have been more than usually violent. This has been specially the case in Holland, where the safety of the dykes is menaced by these pests, and it has been thought that their relative abundance depends to some extent upon the density and consequent saltness of the sea-water. The years 1730, 1770, 1827 and 1858–59 were remarkable in this way.

Mention has already been made of certain small crustaceans, which prey upon timber in sea-water, the sea-louse, or *Limnoria lignorum*, abounding on the English coasts, while closely allied species infest the waters of the Tropics. The Limnoria is more hardy than the Teredo, and is found in the colder seas, right up to the Arctic Circle. It attacks the surface of the wood, especially the softer parts, and bores out a short tunnel, less than half-an-inch in length, so as just to admit its body, which is the size of a grain of rice. In colour it generally matches that of the timber on which it works. These minute crustaceans bore their holes so close together that the entire surface of the wood is honeycombed, and speedily crumbles away by the action of the waves, leaving a fresh surface for attack. In a piece of wood twelve inches square no less than 54,000 perforations have been counted. The Teredo and Limnoria often work together on the same pile, the Teredo burrowing in the direction of the grain of the wood and the Limnoria making its holes at right angles to the surface.

This crustacean has a range of action from about half-tide level down to the sea-bottom, and it selects fir or pine logs rather than harder wood. It will devour pitch-pine logs to the depth of half-an-inch per annum on the northern coasts of the British Isles. At Hartlepool, where the North Eastern Railway Company have provided extensive timber ponds for the storage of imported logs, fresh water has to be pumped into these ponds in order to dilute the sea-water to a condition in which the Limnoria will no longer thrive in them.

The Chelura, a small shrimp-like creature preying on timber, swims on its back, and can jump as well as swim, while the Limnoria can swim, crawl and jump. The Sphæroma, found in the United States and in Australia, will live in comparatively fresh water, in the estuaries of certain rivers, and destroys the whole surface of the wood much in the same way as the Limnoria, which it somewhat exceeds in size.

The Pholas, a species of mussel, which generally bores into stone, will sometimes find its way into timber in the Tropics. It makes its shallow tunnel, or rather niche, at right angles to the surface, and forms a cavity or depression, seldom exceeding two inches in depth, and from half- to three-quarters of an inch in diameter. No other object than shelter and security from its foes can be the cause of these perforations, since stone, or more rarely concrete,[1] is commonly chosen for its habitat.

Having thus considered the various animals causing injuries to timber

[1] Minutes of Proceedings Inst. C.E., vol. cvii, p. 194.

immersed in sea-water, it may be well to examine the methods adopted for its preservation from these attacks. From the most ancient times the protective nature of bitumen, or mineral pitch, would seem to have been well known, and when Noah was directed to make an Ark of Gopherwood, he was ordered to "pitch it within and without with 'pitch.'" At a very early date, also, the value of metal sheathing was recognised, and this process was in common use in this country in 1666. Instead of using a sheet of metal, the woodwork was in some cases studded with nails, with broad projecting heads, but unless the so-called "scupper-nails" were driven so closely together that the heads touched one another, they were found to be a very imperfect safeguard against the Teredo and its congeners.

From the earliest records of the "Proceedings," notices are found of the depredations of the Teredo, and of the various steps taken to abate them, and at the date of the foundation of the Institution many plans for the preservation of timber were already competing for public favour. Most of these processes depended upon the possibility of impregnating the cells of the wood with substances capable either of protecting the fibre from decay, or of resisting the intrusions of the various pests preying on timber.

Although Glauber, the eminent German chemist, is said to have advocated various means of impregnating timber with pyroligneous acid as far back as 1657, the earliest patent dealing with the subject would appear to be that of Alexander Emerson in 1737.[1] The ingredients he used were boiled oil, mixed with poisonous substances, and applied hot. In 1754 John Lewis patented the use of specially prepared tar and, in 1768, a patent was enrolled by Humphry Jackson, in which he specified the boiling of the timber for several hours in a very strong solution of calcareous earth, which solution was either to be made in water or in "acid of vitriol."

Coming down to the more recent processes, John Howard Kyan obtained a patent in 1832 for preserving vegetable substances by soaking them in a solution of mercuric chloride, or "corrosive sublimate," a virulent poison, and, after further experiment, he claimed the use of this process for timber in 1836. A year later, in 1837, Margary patented the use of acetate or sulphate of copper, in which the materials to be treated were soaked, and the next year, in 1838, the employment of chloride of zinc was claimed by Sir Wm. Burnett. He stated that this salt forms an insoluble compound with the tissues of the wood, which latter is to be placed in hermetically sealed cylinders and subjected to the zinc solution under pressure.

Payne's process,[2] which involved the use of two different solutions, was introduced in 1841. Payne's theory was that the substances employed by him in succession were such as to react the one on the other in the pores of the wood. One of the substances was first to be forced into the timber under pressure and subsequently drawn off. He

[1] Minutes of Proceedings Inst. C.E., vol. xii, p. 215.
[2] *Ibid.*, vol. xii, p. 217.

then introduced the other fluid to complete the process. He mentions the use of sulphate of iron and carbonate of soda, with a small proportion of iron oxide. When carefully applied on the Continent this system met with considerable success, though opinions concerning its value differed much in this country.

The most notable of all the processes brought forward for the preservation of timber, having special reference to teredo attacks, was undoubtedly that involving the use of the heavy oils of tar, which are commonly known as "creosotes." The first to propose the employment of these products was Franz Moll, who took out a patent in 1836 for injecting into wood, in closed iron vessels, the coal-tar oils, first in the state of vapour and afterwards in the ordinary liquid condition. The practical adoption of the process is, however, due to Mr. John Bethell,[1] though his patent, dated July, 1838, does not mention the words "creosote" or "creosoting." He specifies a list of no less than eighteen different substances, mixtures or solutions, some being oleaginous or bituminous, as also some metallic salts. Among the various ingredients he enumerated coal tar, which is to be thinned with one-third to one-half its quantity of "dead oil," distilled from coal-tar. This was really the origin of the so-called "creosoting process." The Minutes of Proceedings of the Institution of Civil Engineers contain constant references to the employment of creosoted soft timber for piles, dock-gates and other structural purposes, where the attacks of the teredo were to be feared, and the evidence of its value as a preservative are very emphatic. In certain cases it seems to have failed, though failures could often be attributed to imperfect impregnation of the timber, to the employment of unsuitable qualities of creosote, or to the use of insufficient quantities. Hard timber is not creosoted, as impregnation is much more difficult than in soft woods.

Excellent accounts of the different systems of treating and preserving timber are to be found in the Minutes.[2] It seems to have been for a long time a moot point whether it was advisable to make use of the thicker and heavier rather than the lighter oils. Mr. Bethell himself stated in November, 1864, that "the creosoting process was not, as often described, a chemical process entirely," though creosote did produce chemical changes in the tissues of the wood, "but that was not his only idea when he introduced the process, his object was to fill the pores of the wood with a bituminous, asphaltic substance, which rendered it waterproof, etc." The practice, soon after the process was adopted, was to mix the heavier "London oils" with a small percentage of the "country oils," which were thinner, lighter, and more volatile, and contained in most cases a larger proportion of the ordinary tar-acids. As time went on, the country oil became popular and found its way into specifications, because this oil was injected with less trouble, and the timber looked cleaner and less "muddy" after treatment. Dr. Letheby, who devoted much time and study to the subject of the coal-tar derivatives, gave good scientific

[1] Minutes of Proceedings Inst. C.E., vol. xii, p. 218.

[2] *Ibid.*, vol. xii, p. 206, and vol. lxxviii, p. 97.

reasons for the preference expressed for the lighter oils,[1] and he concluded that the efficiency of the process was largely owing to the carbolic acid present. He stated that those portions of the dead oils distilling over between 360° and 490° Fahrenheit were the best for the preservation of the timber, and he desired to exclude as far as possible the use of the naphthalene and para-naphthalene.

In the discussion of Mr. S. B. Boulton's paper at the Institution of Civil Engineers in 1884, the views of the leading experts and chemists on the results of the process, and on the nature of the substances in creosote on which the chief reliance should be placed were fully set forth, though the requirements of the railway engineer in the matter of sleepers were mainly studied. The Author of the Paper, in summing up the ultimate results of the discussion and correspondence, was able to make out a strong case for the use of the heavier oils, and the comparative inefficiency of the lighter oils and tar-acids. There can be no doubt that, for timber intended to be immersed in sea-water, the solubility of the acid constituents must not be lost sight of.

Some special references to the failure of timber structures in sea-water found in the Minutes may now be recorded. One of the earliest instances mentioned is the account of the failure of the pier-head of Old Southend Pier,[2] which was constructed of 38 Memel fir piles, 12 inches to 14 inches square, driven to a depth of 8 to 10 feet into sand or blue clay. These piles were sheathed with copper, and well coated with pitch and tar. Only six months after the completion of the work, the teredo was found to be present, and within twelve months the "worm" was reported to have seriously injured most of the piles above the copper sheathing, while, at low water of neap tides, it was ascertained that nearly all the piles were damaged at the base. In consequence of local denudation of the coast-line, after the piles were driven, the copper no longer reached to the sea bottom. In a few years more, all the piles were completely eaten through, and the structure had to be replaced by a pier-head, formed partly with cast-iron piles, and partly with oak timber. At Southend the mischief was done both by the teredo and the limnoria, but no attempts appear to have been made to impregnate the timber with preservative solutions.

In some of the earlier discussions on the attacks of the teredo, engineers expressed so much dread of its ravages that in many cases plans were changed when it was known that the "worm" was likely to occur. Thus Sir John Rennie[3] stated that the dock gates at Sevastopol were originally intended to have been made of timber, but owing to the presence of the teredo they had been constructed of iron. Some of the earlier opinions expressed with respect to the creosoting process were very conflicting—Sir John Hawkshaw was opposed to all preservative processes, as tending to weaken the timber, or to render it brittle. Sir S. M. Peto had examined over 1,000 creosoted piles at Lowestoft, and found that not

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[1] Journal of the Royal Society of Arts, vol. 62, p. 286, *et seq.*

[2] Minutes of Proceedings Inst. C.E., vol. ix, p. 23.

[3] *Ibid.*, vol. vi, p. 54.

one had been injured by the worm. Mr. I. K. Brunel affirmed that creosoted wood had been destroyed by the teredo at Plymouth. Mr. J. M. Rendel said that, while at Southampton Royal Pier pine baulks 14 inches square were reduced to about 4 inches by 4 inches in four years, creosoted timber had remained perfect from February, 1848, to January, 1853. He considered it necessary, in order that the treatment might be deemed to be effectual, to weigh each log in and out of the creosoting tank, so as to test the amount absorbed by actual weight.

Engineers in America have devoted considerable attention to the employment of creosote and other preservatives for timber, and Mr. O. Chanute, in a Paper read before the American Society of Civil Engineers[1] in 1900, contrasted the procedure in the United States with the practice of the various European countries. A Paper was read before the same Society in June, 1900, by Mr. F. A. Kummer,[2] describing the creo-resinate process, under which, in lieu of using creosote alone, a mixture is prepared of 38 per cent. of dead oil from coal tar, 2 per cent. of formaldehyde, and 60 per cent. of melted rosin. The rosin is added to render the preparation absolutely waterproof, and the formaldehyde is employed to strengthen the antiseptic action of the compound. It appears, however, that a similar preparation, tested by Mr. Putnam at the Galveston Wharf Company's premises, proved to be a complete failure. His mixture was one-third rosin to two-thirds creosote, and the result was that the rosin so destroyed the quality of the oil that, except for the colour, it was impossible in a short time to detect that creosote had been used. The timber, prepared as above described, was demolished in two years, and much the same result ensued in the case of some test-pieces, four inches square, affixed to piles at Biloxi. It was reported, in this case, that the use of the rosin seemed almost to impart a relish to the wood, as far as the teredo was concerned.

The merely temporary efficacy of creosoting timber was displayed in the case of some piles, which, after absorbing 10 lb. of oil per cubic foot, remained free from attack for four or five years; but, at a later period, they became infested with the limnoria, and after having been only twelve years in the water, were reduced to one quarter of their original bulk.[3] The *Limnoria lignorum* is known in some places as the "surface worm," though it is more nearly allied to the shrimp tribe. Timber covered with sand remains untouched by the teredo and other pests.

In Australian waters at Port Darwin,[4] jarrah piles were found, after an immersion of six months only, to have been so severely attacked by the teredo that it was decided to sheath all timber with Muntz's metal up to the high-water line. Karri timber drives better than jarrah when used for piles, but is far inferior to it in durability. Billian wood resisted the teredo for three years, but in four years karri piles were completely destroyed at the lower ends. Cypress pine is the only native Australian timber which seems to be completely immune. It is stated that at

[1] Proceedings of American Society of C.E., vol. xxvi, p. 900.
[2] *Ibid.*, vol. xxvi, p. 552.
[3] Minutes of Proceedings Inst. C.E., vol. xxvii, p. 573.
[4] *Ibid.*, vol. ciii, p. 337.

Otago[1] the use of jarrah timber from West Australia was not considered, as it was known to be attacked by the teredo. In the account given of the Tampico Harbour Works[2] one of the speakers said that when Sir J. Coode commenced the harbour works at Colombo, about twenty years previously, he erected a temporary jetty, at which to land materials. The Baltic fir timber of which the jetty was constructed was creosoted with 12 lbs. to 14 lbs. of oil per cubic foot, but in two years the piles were so riddled with teredo boreholes that the jetty had to be replaced by a work in concrete. His experience was that no preservative was proof against the ravages of the "worm" in some tropical waters. The same thing was true at San Francisco, where the whole of the harbour works were gradually being destroyed by the teredo. In the case of turbid waters, in the estuaries of great rivers, in which much sediment is carried out into the sea, timber piles do not suffer in the same way as in clear water, and it is asserted that certain estuaries are entirely free from the teredo. This is the case, for instance, with the Bristol Channel but in a few of the warmer rivers of the East the teredo is said to be found even in fresh water.

Evidence of the failure of timber which was stated to be greenheart is afforded by the experience gained at Algoa Bay, Cape Colony.[3] Here the piles, fenders, and walings of so-called greenheart timber, which had been in use only for eight years, were found to have been attacked in several instances by the teredo, and at every scarf, and where the vertical fenders were cleated to the walings, the limnoria had completely destroyed the timber under the surface. Indeed, in some instances the fenders could readily be removed by the hand. In the case of some dry docks at Riley's Hill,[4] on the Richmond River, New South Wales, some of the hard and resistant native timbers fared badly. "Blackbutt" piles, used in the cofferdam, were eaten throughout by the teredo and the "Bloodwood" piles were much damaged in 8 months. The piles of Oregon pine in the dry dock were also destroyed. The "Scrub-box" piles stood well, and an outer row of piles of "Turpentine wood," which is known to have a great power of resistance, were untouched after an 8 months' exposure. The efficacy of the resistance is said to be due in this last case to some special chemical substance in the tissues. It is unnecessary to multiply instances of the failure even of the hardest kinds of timber in the warm seas of the Tropics, for even the most resistant species of wood perish in time. This may be due to the gradual washing out of some astringent or other principle in the sap-vessels, though woods like jarrah and greenheart last better in home waters than in warmer seas. Thus we read that the worm shows little action on blue gum piles at Dover, and, generally speaking, the greenheart piles were found to be sound and dry, after many years immersion in the sea.

Some references have already been made to the various plans of protecting timber from attack by means of sheathing, scupper-nailing,

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[1] Minutes of Proceedings Inst. C.E., vol. cx, p. 315.
[2] *Ibid.*, vol. cxxv, p. 264.
[3] *Ibid.*, vol. cxxx, p. 265.
[4] *Ibid.*, vol. clii, p. 193.

and similar external coatings. It is stated that on the Lim Fjord,[1] in Denmark, where the worm is very active, timber is rendered immune from teredo- and limnoria- attacks by driving into it ungalvanized wire pins, 1½ inches long, to the number of 400 in every square foot of surface, whereby the wood becomes speedily impregnated to a depth of about 2 inches with rust, which repels the foe. Timber piles and wharves have also been successfully protected by the employment of reinforced concrete formed round interlaced rods and wires on specially prepared framework. In the warm seas of Florida piles have been encased with stoneware drain pipes, and in a Paper[2] read before the American Society of Engineers, in November, 1893, a description is given of the protection of 4,274 piles on the Bay St. Louis and Biloxi Bay Railway by this means. The pipes were carefully jointed and filled with sand. In some cases rough wooden moulds were fixed round the piles, or even empty cement casks, and the space between the outer shell and the pile was filled up with cement concrete. The danger of a simple casing of concrete is that it is liable to be chipped away by floating logs or damaged by collisions.

It is pointed out in the Proceedings of the Institution[3] that sheathing of copper or Muntz metal is also exposed to this risk, and that the use of ordinary drain pipes is unsatisfactory, as frequent faucet and spigot joints are apt to impede the sinking of the pipes. The earthenware pipes have, moreover, very little strength longitudinally, and good jointing is difficult. Pipes on the Monier system have therefore been employed; these were formed of reinforced concrete, and were used for the piles of the traffic bridge over Cockle Creek, near Sydney, New South Wales. The piles were of ironbark timber, about 40 feet long, and 14 inches in diameter, and the Monier pipes were threaded over the head of the piles *in situ*. The pipes, which were 21 inches in diameter, were jointed with a cover of wire netting and cement, and the space between the pipes and the pile was filled with sand. This was finished with 9 inches of concrete at the top to form a cap.

Fairly good results have been obtained in warding off the inroads of the teredo by charring the entire surface of the timber below the water-line, and, at San Francisco, some piles treated with a coating of asphalte, marine cement and Portland cement, made up into a mixture and applied hot with a brush have stood well. Another plan of protection has been successfully employed by the manufacturers of a paraffin paint. After the timber has received a thick coating of this special paint, a jacket is placed round the piles formed of coarse canvas, thickly spread with the same paint and nailed on to the timber with copper-plated nails. Piles thus prepared have resisted the teredo for 8 years, in places where an ordinary untreated pile is eaten away in from 4 to 6 months. Another plan is to apply coal tar hot to the surface of the timber, and then to fasten on stout felt, saturated with tar, fixed to the wood with galvanized nails. An outer protection to the felt is formed of red wood battens,

[1] Minutes of Proceedings Inst. C.E., vol. clix, p. 401.
[2] Transactions of American Society of C.E. vol. xxxi, p. 221.
[3] Minutes of Proceedings Inst. C.E., vol. cxlii, p. 288.

secured with stout wire. Many of these expedients can only be regarded as of a temporary character, and the work needs constant supervision.

The extensive use of iron and latterly of reinforced concrete has tended to render the employment of timber in the form of piles in harbour works and jetties much less frequent, and the protection of timber from teredo attacks is no longer of the same importance, as it once was. It may be pointed out in conclusion that both timber and other structures are in many places, as we have already seen, protected by marine growths, which form solid and durable incrustations around them and thus render them safe from the various attacks of which an account has been given.

II. CONCRETE.

It was not until many years after its adoption for use, mainly in foundations, that engineers began to build walls and employ large blocks of Portland cement concrete for structural purposes. Lime concrete, in which so-called "hydraulic lime" was mixed with trass and puzzuolana, had been used with success in marine works even from the times of the Romans, but the employment of Roman and later of Portland cement concrete for works under water found at first but little favour. Engineers on the Continent, in their search for a material to be used as an artificial stone, were early in the field, and we read of huge blocks being made in the seventeenth century by M. Lebrun, an architect of Toulouse, from a mixture of cementitious lime and sand, rammed into moulds with a minimum amount of water.

Though of course many notices of the use of concrete in marine structures occur in the earlier volumes of the Minutes, it may be convenient to take, as the starting point, the Papers read and discussed in November, 1886,[1] because on that occasion a thorough and exhaustive account was given of the various methods of employing concrete, deposited direct in the sea, as it was mixed, or made into blocks and allowed to set before use. Many large and important works were then described, and the full discussion of these Papers may be taken as representative of the views of engineers at that period.

Confidence in the use of Portland cement for purposes of construction may be said to date from the time of the publication of the Paper by Mr. Grant, in 1865,[2] on the "Strength of Cement," and his experiments and tests resulted in the establishment of a safe standard, by means of which the value of the material could be judged. The Papers on "Concrete Work under Water," to which reference has been made, published 21 years later, in 1886, show that extensive use was then being made of this material in all parts of the world, and it was already regarded as suitable for almost every kind of work in sea-water.

It was no doubt the destructive action of the waves on concrete only partially set which led, in the first instance, to the employment of the material in the form of large blocks, which were allowed to become indurated on land before they were placed beneath the water, and

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii, pp. 65, 76, 92, 114, 123 and 134.
[2] *Ibid.*, vol. xxv, p. 66.

though made comparatively small at first the blocks were gradually increased in size, to render them better able to resist the effects of storms. In the efforts made to employ recently-mixed concrete, it was usual to increase largely the proportion of cement to aggregates, to allow for the washing away of the cement in troubled water, or to enclose the concrete in sacks or bags, sometimes very large in size, as also to employ frames of timber, carefully caulked, and made water-tight, to enable the cement to become properly set.

In the account given of the Colombo Harbour Works[1] mention is made of the use of large concrete blocks, while on the sea-berm of rubble the upper slope was protected by means of an apron formed of large bags of concrete.

The harbour works at Newhaven[2] involved the use of 100-ton monoliths of plastic concrete, enclosed in jute sacks, which the Author proposed to call "sack-blocks," deposited by means of a special hopper-barge. This system was explained to be a development of the plan originally adopted at Aberdeen in 1875. It was stated that the success of the system of sack-blocks depends on the rapid mixing of the concrete. On the foundation of the sack-blocks at Newhaven a monolithic mass of concrete, formed of 1 part of cement to 8 parts of shingle, built up from sea bottom to low-water level, was used for the breakwater.

The deterioration of the concrete work at Aberdeen was very fully described in the Paper on "The Influence of Sea-water upon Portland Cement Mortar and Concrete"[3] in 1891. It was shown that the concrete used at Aberdeen for the different works varied considerably in strength—the richest concrete was composed of 1 of cement, 2 of sand, and 3 of stone, and some of the concrete, which appears to have proved of a porous character, was made of 1 part of cement, 4 of sand, and 4 of stone, with embedded rubble or "displacers." Some of the backing had even 9 parts of aggregates to 1 part of cement. When the dock was opened there was a considerable amount of leakage, in spite of a "water-tight" lining of 3 parts of clean rough sharp sand to 1 of cement, 4 inches in thickness. The leakage gradually increased in volume, coming through the mortar of the concrete walls, and the entrance walls began to swell, opening the joints of the sill-stones and cracking the plaster. About two years after the completion of the dock, it was reported by the engineer that the Portland cement concrete entrance-walls had expanded $2\frac{3}{4}$ inches on the height of the walls; that their surfaces had become cracked and bulged; and that the joints of the caisson quoin-stones had opened up, causing considerable leakage.

The Author of the Paper on the above work asserted that "the only certain and permanent method of building large masses of concrete or masonry for immersion in sea-water is to make the entire mass impermeable," and he considers that nothing weaker than 1 part of cement to 4 parts of aggregates ($1\frac{1}{2}$ sand and $2\frac{1}{2}$ stones) should be

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii, p. 76, *et seq.*
[2] *Ibid.*, vol. lxxxvii, p. 92.
[3] *Ibid.*, vol. cvii, p. 73.

allowed, for no weaker mixture than this "can be considered permanently safe under the pressure of sea-water." The Aberdeen concrete was spoken of later, by one who had seen the works in course of construction, as "nothing more nor less than a huge filter."

In the same volume a Paper by Dr. Michaëlis, of Berlin, is printed, entitled "The Behaviour of Portland Cement in Sea-Water."[1] Here also the importance of an impermeable mixture is emphasized, because "the salts dissolved in sea-water attack hydraulic cements with energy, if the water is able to permeate or wash through the mass continuously." The Author maintains that "aluminate and ferrate of lime are not only decomposed and rapidly softened by sea-water, but they also give rise to the formation of double compounds, which in their turn destroy the cohesion of the mass by producing cracks, fissures and bulges. The salts contained in sea-water, especially the sulphates, are the most dangerous enemies of hydraulic cements." Dr. Michaëlis states that "the separation of hydrate of magnesia is only the visible, but completely innocuous, sign of the chemical processes to which reference has been made."

Some of those taking part in the discussion on the Aberdeen failure insisted upon the danger of over-limed cements, which were necessary to comply with the high tensile strength then being demanded by engineers, and some authorities were of the opinion that small percentages of magnesia in Portland cement rendered it unreliable; but this was not demonstrated by actual tests. It appeared to be generally admitted that, for work in sea-water, porous concrete contained in itself the elements of failure, and that concrete made impervious to water was always best. One of the speakers alluded to the large number of examples of sound work in concrete, where the "mysterious magnesian malady" had not broken out, nor had it "in scores of foreshore and sea-works in cement concrete scattered all over the world." The inference, he said, was that "in the works which had failed, either the cement was defective, or it was improperly handled."

With respect to the use of blue lias lime in concrete and mortar for sea work, reference was made to failures at Hartlepool and at Sunderland.[2] The mortar at the former place was composed of 1½ part of blue lias lime, 1½ of clean sand, and ½ of forge cinders. The lime was made from Aberthaw pebbles, collected on the shore at Penarth, and brought by ship to West Hartlepool, where it was burnt in kilns and ground with the other components in mortar mills. For the first nine years during construction the mortar was found to be harder even than the stone, but, after water was let into the dock, serious cracks and bulges in the wall were noticed. On examination the whole of the mortar below high-water mark seemed to have expanded and become as soft as putty, for a considerable distance from the face; in the upper part of the work it remained as hard as ever. Another similar failure of lias lime mortar occurred in the old walls of the South Dock at Sunderland, built in 1850, and pulled down in 1887 for the construction of a new entrance. On the

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[1] Minutes of Proceedings Inst. C.E., vol. cvii, p. 370.

[2] *Ibid.*, vol cvii, p. 125.

other hand the blue lias lime mortar used at the Tyne dock was found, when subsequently pulled down, to be as hard as possible, the only difference in the specification for the two descriptions of mortar was the use of forge-cinders at West Hartlepool, instead of the puzzuolana, employed at Tyne dock. At the Barry Docks, where an immense quantity of blue lias lime mortar was employed, care was taken to have the lime thoroughly slaked for a considerable time before use, and to employ an abundance of water for the mortar. Here the results, after six years' experience, seemed entirely satisfactory. The proportions adopted were 1 of lime, $1\frac{1}{2}$ of sand, and $\frac{1}{4}$ of hard-burnt clay, all ground together in mortar mills.

As early as the year 1862 Dr. B. B. Stoney, in a Paper read before the Institution of Civil Engineers of Ireland, had called attention to the failure of a wall constructed in rubble masonry, with feebly hydraulic lime, near Pigeon House Fort, on the river Liffey. This wall had been built about one hundred years before, and it was found that in consequence of the action of the sea-water the mortar had in certain places disappeared, leaving the dry rubble with no jointing of any kind. This was proved by means of analyses carried out by Professor Apjohn to be due to the gradual conversion of the calcic hydrate, or that part of the lime not in combination with carbonic acid, into magnesium chloride. The professor was also of the opinion that the magnesium chloride in the sea-water had by double decomposition gradually converted the silicate of lime into calcium chloride and silicate of magnesia. The former compound being very soluble had been washed away by the waves, while the silicate of magnesia remained in a loose state in the disintegrated mortar. The views of Burnell and of Vicat were quoted on the subject of the changes brought about in mortars by the presence of magnesia. Reference is also made to the superiority of lias limes, such as those of Aberthaw, which are eminently hydraulic, as also to Roman and Portland cement for marine construction as compared with the lime used for the retaining wall on the Liffey. The relative proportions of the clay and lime are in the Aberthaw lime 1 to 7·5, in Roman cement 1 to 2·7, in Portland cement 1 to 2·2, whereas in the Dublin lime the relative proportions were 1 to 13·3.

Further troubles, ascribed to the "presence of magnesia in large quantities in the work," arose in connection with the Alexandra Graving Dock at Belfast, opened in 1889, and are set forth in a Paper[1] read in November, 1892. Here, it was observed, soon after the completion of the work, that cracks were being formed in the concrete, which gradually became wide and allowed of the exudation of water highly charged with saline matter. The cracks increased in number and size, and the floor of the dock, which was composed of concrete 10 feet in thickness in the centre, also showed "symptoms of disruption." In June, 1890 an examination was made at the request of the Belfast Harbour Commissioners, when it was ascertained that the mischief was due to magnesia, conveyed by sea-water, which found its way from the adjacent

[1] Minutes of Proceedings Inst. C.E., vol. cxi, p. 59.

tidal river and penetrated through the sandy backing into the lower portions of the concrete. The magnesia abstracted in an altered form, the lime from the Portland cement contained in the concrete and the chemical action thus set up would naturally lead to the disintegration of the concrete. The suggested remedies involved the cutting away of all the defective concrete of the side-walls and floor, and the substitution in place thereof of a superior rich Portland cement concrete, so as to render the works as impervious as possible, and thus to prevent the continuous influx of sea-water.

In the course of the discussion on this and several other Papers dealing with the construction of graving docks, the speakers criticised the absence of clay backing, or a rendering at the backs of the walls with Portland cement or asphalte, and fault was found with the composition of the concrete, which was assumed to be unduly porous. It was considered, moreover, that the foundations should have been carried down through the running sand into the boulder clay beneath. In very large numbers of cases cited, cement concrete had been used for dock-work with complete success. It was pointed out in conclusion "that it was only where the concrete walls were subjected to the unbalanced pressure of the tidal water that the destructive influences appeared to take effect."

In his Paper on "The Action of Sea-Water upon Hydraulic Cements," written nearly thirty years since, Dr. Michaëlis points out that Portland cements contain considerable quantities of lime which is not in stable combination with silica and alumina, the calcic hydrate amounting in some cases to 33 per cent. As the result of numerous experiments he urged the importance of the addition of puzzuolana or trass to cements which have an excess of uncombined lime, when used in marine work.

From time to time the monolithic masses of concrete for use in the sea became increased in size; thus the concrete blocks used for the breakwater at Zeebrugge Harbour[1] range from 2,500 tons to 3,000 tons in weight. These blocks were built up in metal caissons 82 feet in length by $24\frac{3}{5}$ feet wide, and varying in height from 23 to 30 feet. Even those enormous masses of concrete are liable to injury by rough seas, for it was stated that at Peterhead a section of the breakwater, weighing 3,300 tons, was slewed bodily to the extent of 2 inches, without any dislocation of the block-work. It is calculated that the force of the waves needed to produce this result must have exceeded 2 tons per square foot. An observation of the height of the waves recorded during a great storm at Peterhead was 40 feet from crest to trough. It was stated at the Paris Navigation Congress of 1900 that the caissons at Zeebrugge had a cavity in which 2,000 cubic yards of concrete could be deposited when the caisson had been placed *in situ*, making a total weight of 4,400 tons.

The International Association for Testing Materials, at their Fifth Congress at Copenhagen in September, 1909, and again in 1912,[2] considered the results of a series of tests of Portland cement, conducted under the auspices of the Scandinavian Portland cement manufacturers,

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxvi, p. 286.
[2] *Ibid.*, vol. cxciii, p. 373.

by a Committee appointed in April, 1896. For this purpose a very extensive series of blocks, formed of different mixtures of cement and sand, were exposed in groynes at several places on the coast. These blocks were taken up and examined from time to time and the results of the tests, which were carefully tabulated, were generally favourable.

The danger of electrolysis and the consequent attack on the metallic re-inforcement used with concrete has recently attracted a considerable share of attention. It is obvious that the possibility of mischief being caused by stray currents can scarcely arise in the case of concrete immersed in the sea, but for ships constructed of re-inforced concrete, which are now being built, this matter will require consideration. Experiments have shown that even with very feeble currents the steel bars, in the presence of moisture, may rapidly become coated with rust to such an extent as to cause the disruption of the mass.

In a recent Paper dealing with the corrosion of steel wharves at Kowloon,[1] near Hong Kong, considerable attention was directed to the use of concrete for the protection of steel joist piles, which after being in place for about 4 years "were found to be corroded in a curious and rather alarming manner." It will be well to discuss the details of this corrosion when dealing with metal work, but, as a remedial measure, it was decided that the piles and lower bracing of the main wharf should be encased in cement concrete. This was done, in the case of the piles, by dropping over them welded steel cylinders, 20 inches in diameter, which were driven down into the mud with an 8 cwt. wooden "dolly." Into these cylinders Portland cement concrete, mixed in the proportions of 1.2.4, was lowered through the water in metal hopper-boxes. This concrete set extremely hard, and was found to adhere strongly to the pile. The wharf superstructure was coated with concrete by encasing each member in temporary wooden moulds, by means of which a cover of Portland cement concrete of the above composition, $2\frac{1}{2}$ inches in minimum thickness, was provided throughout. On inspection of the work, about a year later, no superficial deterioration of the concrete was evident, but 3 years afterwards obvious signs of corrosion were apparent, and on cutting into the mass a very unsatisfactory condition of the steel was revealed. Rust-scale, about $\frac{1}{16}$ inch in thickness, was found on the steel members, the concrete was damp, though hard and compact, and in some parts the steel was coated with wet rust, even in places above high-water level. It was stated that the limit of serious rusting may be taken as being at high-water level of neap-tides; below that level the corrosion diminished rapidly down to mean-tide level, and there it practically disappeared. On the strength of these observations the author condemns the use of concrete as a protection for steel.

In the course of the discussion it was shown that the use of so-called "sleeves,"[2] composed of an outer casing of metal, filled in with concrete, surrounding the iron piles, has served as an effectual protection to the vulnerable parts of the metal work in various piers built in the Tropics.

[1] Minutes of Proceedings Inst. C.E., vol. cxcix, p. 133.

[2] *Ibid.*, vol. cxcix, p. 158.

The structure at Kowloon could in no sense of the word be called a "reinforced concrete structure," and it seemed inadmissible to compare it with reinforced concrete properly designed and carried out.

In a lengthy correspondence on the subject of these and other reinforced concrete structures, some of the most recent opinions on the subject are set forth. One of the Papers on this occasion dealt with "concreting in freezing weather and the effect of frost upon concrete,"[1] a branch of the subject which only comes into consideration as respect work in sea-water in far northern latitudes. In a Paper on the "White Star" Dock at Southampton,[2] much attention was directed to the subject of the use of concrete under water, and it was stated, in the course of the discussion, that "even under the most favourable circumstances, with perfectly still water, and no current, the deposition of concrete under water could not be entirely depended upon for sound work." The adverse factors were thus summed up—the loss of cement washed out of the concrete in its passage through the water, and the screening effect which follows the discharge of the mass from the skip, when the larger stones roll down the sides of the heap and form a deposit, at the base, of coarse materials with a deficiency of finer binding matters and cement. No subsequent trimming can be carried out at the sea-bottom, with due efficiency, and thus there is always an element of uncertainty as to quality, and consequently of true value, as a structural expedient, in passing unset or "green" concrete through water.

III. CAST IRON, WROUGHT IRON AND STEEL.

The employment of metal work for various structures in sea-water naturally followed in the same sequence as its use on shore. First we have the somewhat timid and tentative adoption of cast iron for piles, columns and piers, later the extensive introduction of wrought iron for almost every possible purpose, and lastly the use of steel, where weight-saving and lightness of construction were considered matters of importance. The most recent employment of metal work, as a reinforcement for concrcte structures, has lately received much attention, partly because it is claimed that iron and steel, properly embedded in cement concrete, are safe from corrosion, and partly because the various conditions arising from the use of these metals in concrete immersed in sea-water present problems needing special study.

Among the earliest records of the Institution of Civil Engineers an account is given of the valuable series of investigations of Mr. Robert Mallet,[3] who had undertaken, in the year 1839, to enquire on behalf of the British Association as to "the corrosion of cast and wrought iron in water." His classic experiments which extended over a number of years were at the time of his Paper still in progress, and his communication took the form of a series of tables, in which are set forth the results of

[1] Minutes of Proceedings Inst. C.E., vol. cxcix, p. 141.
[2] *Ibid.*, vol. cxcv, p. 42.
[3] *Ibid*, vol. i (1840), p. 70.

the "chemical or corroding action" of sea or fresh water, under five several conditions, in a period of 22 months. Five sets of tables are so co-ordinated with each other as to form a connected and comparable whole. These show the relative rates and absolute amount of corrosion of cast and wrought iron (1) in clear sea-water; (2) in foul sea-water; (3) in clear sea-water, at a temperature of 115° F.; (4) in foul river water; and (5) in clear river water.

The corrosive action of water and air combined produced on the surface of the test-pieces a state of rust possessing one or other of the five following characteristics, according to his classification: 1, uniform; 2, uniform with plumbage; 3, local; 4, local pitted; and 5, tubular. In certain cases two or more of these characteristic appearances were combined. These facts were ascertained with reference to eighty-two different specimens of British and Irish Cast Iron. Every sample was described as respects its external character, mode of casting, specific gravity, together with dimensions and weight before and after immersion, with the calculated loss of weight per square inch of surface. This loss is referred to the weight of a standard bar, and the weight of water absorbed to that of clear water. All the results are carefully tabulated.

The five tables contain also the results in the case of certain descriptions of cast iron protected by one or other of ten different kinds of paints or varnishes, showing the amount of corrosion as compared with unprotected metal surfaces. Another table gives a general comparison of the foregoing results for specimens of iron 1 inch thick, and reduced to one common or equal period of immersion. A seventh table gives the average loss of all varieties of cast iron, expressed per square inch of surface. Table VIII. shows the average calculated amount of corrosion (assumed for this purpose to be uniform) of various specimens of cast and wrought iron, per superficial foot, at the end of one century.

From these tables it appears that the metallic destruction, or the corrosion of iron, attains a maximum in clear sea-water at a temperature of 115° F.; the loss is nearly as great in foul sea-water, and shows a minimum in clear fresh river water. Some observations on iron piles exposed to tidal action at the mouths of rivers seem to indicate that, in consequence of the formation of a "Voltaic pile," the upper part is preserved while intense corrosion of the lower part ensues. For protection, it is advisable that the lower part of the pile should have increased scantlings. In the case of foul sea-water, it is pointed out that increased corrosion is due to the presence of putrefying animal matter, and the formation of sulphuretted hydrogen, and hence the rapid corrosion of iron in the sewage water of large cities.

Wrought-iron undergoes the greatest loss in warm sea-water, and the rapid corrosion of marine boilers, where salt is present, is evidence of this fact. It is noticed that the surface of chilled cast iron corrodes faster than that of the same quality of iron, cast in green sand, and some descriptions of iron give rise to the formation of "voltaic couples." Heavier castings, he says, resist corrosion better than light ones, and the experiments appear favourable to the use of Welsh cast iron for "aquatic" purposes. Generally speaking, the more homogeneous, the

denser, the closer-grained and the less "graphitic" the sample, the smaller is the index of corrosion for any given specimen or make of cast iron.

Some interesting and valuable particulars are given of the preservative effect of various paints and varnishes used on metal work, and it is stated that asphaltum varnish or boiled coal tar, laid on while the iron is hot, gave the best results under all circumstances.

In Tables IX. and X. figures are given to represent the total corrosion of cast iron in sea-water, when exposed in "voltaic contact" with various alloys, as copper and zinc, copper and tin, or either of these metals separately, stated per square inch of surface. Brass and gun-metal were found to have no protective power over iron in water, but, on the contrary, they promote loss by corrosion. The Tables show the loss of cast iron in sea-water in contact with copper and various alloys, and reference is made to "electro-chemical" protection. As a side issue the effect is shown of strong compression of the metal during the process of casting. By thus imparting density to the cast iron the liability to corrosion is diminished. This is set forth in Table XII.

Three years later, in 1843, Mr. Mallet communicated the results of further experiments upon cast iron, wrought iron and steel to the Institution.[1] During the course of the investigations the samples of metal had been exposed at two separate periods of 387 days and 732 days to the action of the different kinds of water already mentioned, as also to the atmosphere and its precipitations, at Dublin. Cast iron had also been tested. (1) When coated with zinc or galvanically protected by contact therewith; (2) painted and varnished in various ways; (3) when in contact with various alloys of copper and zinc and of copper and tin, as in brass and gun-metal, which are both of them electro-negative to iron in water; (4) where the metallic surface had been modified by chilling, etc., or where the surface or "coat" had been removed by planing. A final Table gives the specific gravities, rigidly ascertained, of all the specimens of cast iron, wrought iron, and steel experimented upon. Much importance was attached by Mr. Mallet to the effects of density as influencing the "ratio of corrosion" in the case of cast iron.

As the results of analyses, corrosion is said to depend not on the proportion of carbon usually present and still less on that of other foreign matters, but upon the condition in which carbon exists in the compound, and upon the state of aggregation of the whole mass. Another factor is the density of the metal, and the voltaic uniformity or otherwise of the surface exposed to corrosion. The rate of cooling in the process of casting influences the liability to corrosion, though hot or cold blast in the manufacture produce but little difference in the "corrodibility" of the metal. Carbon was found to exist in cast iron in two different forms, either as diffused "graphite," in a crystalline form, or as combined carbon. The bright grey iron of high commercial value is less subject to corrosion, when exposed to air or water, than any other quality of the cast metal.

Experiments on wrought iron and steel showed that the samples

[1] Minutes of Proceedings Inst. C.E., vol. ii (1843), p. 171.

consisted of two or more different chemical compounds, "coherent and interlaced," of which one is electro-negative to the other. The electro-positive body is that which suffers first from corrosion. The electro-negative portions of the iron and steel remain bright and hold a perfect metallic lustre until the whole of the other portions of the metal are removed, or have been extracted to a considerable depth, when they begin likewise to oxydate. An account is given of the special attack on various kinds of wrought iron. Foul sea-water, evolving sulphuretted hydrogen, produces a maximum amount of corrosion in the case of wrought iron and steel. Contact of the metal with soft putrefying matter appears to be still more destructive. An account is given of the so-called "plumbago," which is crystallized carbon. The chemical nature of the substances known as rust was fully investigated. Thus the compound with the formula $2\ Fe_2O_3+3\ H_2O$ more or less mixed with spathic iron $Fe\ O\ CO_2$ finally loses water and is converted into anhydrous peroxides. The value of galvanizing with zinc is doubtful except for iron exposed to the air. In foul sea-water the zinc coating is converted into artificial blende—$Zn+Fe+S$, but the zinc paints were found to be the most durable of all those tested.

Much attention is directed to the prevention of corrosion and the fouling of iron ships, and the opinion is expressed that magnetism has nothing to do with the amount of corrosion in iron vessels. It is pointed out that kyanized timber, when in contact with iron in sea-water, has a very destructive action and more than doubles the rate of corrosion. A number of processes advocated for the protection of iron, viz., those of Berry, Neilson, Shore, Elkington and Ruolz, Hall of Bermondsey and Fountain-Moreau were tested, and only that of Elkington and Ruolz was found to possess practical value. In conclusion it is asserted that as uniform absence of corrosion cannot be ensured in iron vessels, the best protection possible from the results of corrosion and fouling must be sought. Iron ships properly protected may be regarded as safer in every respect than the best vessels constructed of timber.

Many examples are found in the Proceedings of the deterioration of cast iron submerged in the sea. Old cannon balls and anchors fished up after many years were found to be quite soft and capable of being cut with the knife, which was also the case with some iron guns, mentioned by Sir John Rennie[1] as having been found off Holyhead in 1822. These were supposed to have belonged to a pirate vessel destroyed there about 100 years before. When found they were quite soft, but, after exposure to the air for a time, they became so hard that they were used "to fire salutes," when King George IV. passed through Holyhead on his way to Dublin. In a footnote, the condition of some iron guns belonging to the "Florida," one of the vessels of the Spanish Armada, fished up off the Coast of Mull, is described. Here, also, the metal had perished. It seems to have been assumed that in the above cases the metal was so acted upon by the sea-water that the carbon was left in the state of "plumbago," after the iron had been completely corroded or dissolved.

[1] Minutes of Proceedings Inst. C.E., vol. iv, p. 333.

In the use of cast iron for piers or piles the deterioration seems to have been much less rapid when the metal was merely exposed to the alternation of the tides, and it was asserted that the cast iron columns of the pier at Gravesend remained in good condition after 34 years.

When discussing the subject of dock gates at the Victoria Docks, it was stated that in the case of the sluices at the Monkwearmouth Dock, where brass worked against iron the metal was found to be wholly destroyed after being in use about eighteen years. Sir John Rennie[1] mentioned that, to the best of his belief, iron was first used for lock gates in the Caledonian Canal by Telford. In these gates the ribs were of cast iron and the other parts of timber. In 1819 Mr. Rennie constructed gates wholly of iron at Sheerness. Some sluices in the Hartlepool Docks, made to work brass against brass, under the direction of Sir John Rennie, were found on examination in 1859 to be as perfect as when first constructed.

In the course of a discussion on marine structures in 1863, Sir F. J. (then Mr.) Bramwell said that it appeared to be assumed that cast iron was an improper material to be used in the sea. He would like to know whether that had been satisfactorily tested in English waters, and whether this might not depend upon the quality (whether grey or white) of the metal. Another speaker stated that he did not consider the danger of the deterioration of cast iron in sea-water to be very serious. In the presence of sulphuretted hydrogen there would be a tendency for the iron to become decomposed, but he found that iron beneath the surface of sea-water was speedily protected by incrustation. Iron exposed to tidal wash, and alternately wet and dry at about the level of half-tides, would waste to some extent.

In a Paper on the Clevedon Pier,[2] it was stated that, with respect to the relative durability of wrought- and cast-iron, there were numbers of cast-iron structures in sea-water which had stood for thirty or forty years without symptoms of decay. Small wrought-iron rods had been found to stand sea-water fairly well. One of the speakers said that he had had occasion to mark out a line of training-bank on the coast of South Wales with small iron rods. These rods were $1\frac{1}{4}$ inch in diameter, and stood 10 to 12 feet out of the sand. They extended about two miles into the sea from the shore-line, and though frequently subjected to heavy breakers they were not corroded. It seems, in the case of round bars, that they became coated with a species of film, resembling galvanized iron in appearance, which served as a protection. On bars with square edges, or arises, liable to be abraded or chafed off, a polished surface, owing to the constant abrasion, continually recurred. Thus fresh coatings of rust were formed, and in time the metal perished.

In the discussion which took place on the occasion of the Paper on the Comparative Endurance of Iron and Mild Steel when exposed to Corrosive Influences,[3] the views of experts at that period were fully set forth.

[1] Minutes of Proceedings Inst. C.E., vol. xviii, p. 520.
[2] *Ibid.*, vol. xxxii, pp. 130, 157.
[3] *Ibid.*, vol. lxv, p. 73.

The Author, as the result of his experiments extending over many years, was of the opinion that the commoner sorts of iron, containing the most phosphorus, resist corrosion far better than the purer kinds; and also that the harder steels, containing the greatest amount of carbon and phosphorus, are better in this respect than the softer and milder sorts. The tests were conducted chiefly with plates and boiler tubes. At that time steel had been in use for ship-building for about twenty-five years. The importance of galvanic action, which was somewhat disregarded by the Author, was insisted upon by some of the speakers, and the part played by the scale of black magnetic oxide was emphasized. It was stated, also, that in the case of marine boilers the protective effect of zinc, properly applied, was very marked. Much important information was collected by the Boiler Committees of the Admiralty and set forth in their various reports, but these did not, as a rule, refer to sea-water corrosion.

Two Papers [1] give the results of careful tests on metals exposed for long periods to sea-water, more especially from the galvanic aspects of the question. They show the amount of corrosion observed in the case of bars and plates of wrought iron and steel in galvanic connection, immersed in sea-water, as also the electrolytic disintegration of the metals exposed to constant electric currents of varied and known intensity, and they distinguish between the effects of simple corrosion and galvanic corrosion. From both of these actions iron and steel suffer considerably in sea-water, and the importance of guarding against accidental galvanic corrosion is shown to be of much moment.

Concerning the chemical causes of corrosion in iron and steel the conclusions of Dr. Crace Calvert [2] are quoted. He says: "Under the conditions described (immersion in the sea) pure and dry oxygen does not determine the oxidation of iron, that moist oxygen has only feeble action; dry or moist pure carbonic acid has no action, but that moist oxygen containing traces of carbonic acid acts most rapidly on iron, giving rise to the formation of protoxide of iron, then to carbonate of the same oxide, and last to a mixture of saline oxide, and hydrate of the sesquioxide of iron."

It would appear from the observed effects of corrosion of tempered steel in sea-water that a hard tempering has a protective influence; thus a hard chisel deeply corroded in the soft part was untouched in the tempered parts.[3] The corrosion was most severe at the line of contact between the tempered part and the untempered metal of the haft. It would seem that tempered and untempered steel, when brought into contact in the presence of salt water, constitute an electro-chemical couple, and this hastens the destruction of the untempered metal.

It had already been remarked that metal work under stress in the open air suffered less from the effects of corrosion than metal not so stressed, and it would appear from the results of a series of tests [4] that

[1] Minutes of Proceedings Inst. C.E., vol. lxxvii, p. 323, and vol. lxxxii, p. 281.
[2] *Ibid.*, vol. lxxxii, p. 282.
[3] *Ibid.*, vol. lxxii, p. 402.
[4] *Ibid.*, vol. cxviii, p. 356.

the same is the case with metals immersed in sea-water. The Author concludes that the stresses applied to the metals, examined by him for corrosion, altered their structure, rendered them harder in nature (as shown by their increased tensile strength) and hence less liable, in the strained condition, to be acted upon by sea-water, or other waters, than in their ordinary normal or softer condition. He found, as the outcome of his experiments, which were conducted with wrought iron bars and shafts, and many different qualities of steel in bars and shafts that in general the steel suffered more from the effects of corrosion than the iron. It was also noticed that the corrosion was increased in the steels in proportion as the percentage of combined carbon was greatest.

Considerable discussion was evoked by a Paper contributed by Mr. Dewrance on corrosion of marine boilers[1] which dealt with this matter rather from the aspect of the failure of the boiler tubes in water-tube boilers. Much light was thrown by analysis on the composition of the various oxides of iron, and a great number of experiments were conducted by the author in iron dishes, in which the various liquids were boiled. In order to establish uniformity of aeration, a glass tube was caused to deliver air into the solution. He employed distilled water, to which various salts were added, and also sea-water with zinc sulphate, soda, magnesium sulphate, magnesium chloride, calcium chloride and sodium chloride and noted the weight of oxide produced by each liquid. It would seem from the various tests that much depends upon the air present in the water in this kind of internal corrosion.

Many experiments were conducted from time to time to test the various systems of securing iron exposed to sea-water from rust, and the results are set forth in Tables. Few of these are more complete than the comprehensive series of tests brought to the notice of the American Society of Engineers[2] in November, 1896. In this case sheets of ordinary boiler-plate steel and many descriptions of alloys were coated with various kinds of enamels, paints and varnishes, ordinary red lead in oil, two kinds of iron oxide paints, iron oxides made up in shellac, ivory black in Japan, "durable metal coating" (a special kind of varnish) and "Sabin" process enamel. The plates were immersed in the sea for six months and then examined. The enamels, applied with a considerable amount of heat, appear on the whole to have given the best results, while the zinc paint was the pigment least acted upon among the paints. It was found that in nearly every case corrosion began at the edges of the plates. Portland cement has long been regarded as a good preservative of iron and steel, and Mr. Scott Russell[3] stated that he had seen cement taken out of the inside of ships, after 18 years' use, adhering to which was the red lead paint and the "skin of the iron," the metal being as sound as the day it was first used.

It has already been mentioned that ironwork in the sea is often protected by dense coatings of oysters and other marine growths, but in

[1] Minutes of Proceedings Inst. C.E., vol. cxli, p. 107.
[2] Proceedings of American Society of C.E., vol. xxii, p. 527.
[3] Minutes of Proceedings Inst. C.E., vol. xxv, p. 129.

the case of some steel wharves at Kowloon,[1] near Hong Kong, very deep pitting, believed to be caused by some "shell fish or other marine growth" has been observed. The saucer-shaped holes, varying in size up to $1\frac{1}{4}$ inch in diameter and $\frac{3}{8}$ inch deep, were full of a black powder said to be sulphide of iron. It was thought that sulphuretted hydrogen, emitted by dead and decaying matter, attacked the iron and caused extensive deterioration. With a view of preserving the metal from further attack, the piles and girders were encased in concrete in the manner described in the section of this digest dealing with concrete. The subject of metallic reinforcement in concrete placed beneath the sea attracted considerable attention in the debate on the above Paper, and some of the speakers insisted upon the need of a specially rich concrete in which to encase the metal. The presence of moisture, owing to the permeability of the concrete, caused a very rapid attack on the metal work. The fact that damage may be done to steel reinforcement by stray currents must also receive attention. It is stated that at Southampton Docks considerable apprehension was caused by deterioration which was taking place after two years in reinforced concrete, but careful investigation showed this to be due to an escape of electric current from the main supplying the electric cranes.

Concerning the relative durability of wrought iron and steel in sea-water, it is necessary to bear in mind the fact that in neither case is it a question of the behaviour of perfectly pure iron, but that with both materials we have to deal with a very complex mixture of the metal with various proportions of chemical compounds and of foreign ingredients, some of which have no doubt considerable influence on the action of sea-water, as tending to promote corrosion. In order to institute a perfectly fair comparison, it would be necessary to obtain samples of both metals identical in composition. In the case of steel, numerous experiments have shown that, in consequence of the phenomenon known as segregation, great differences in the structure and constitution of the metal are found to exist, and owing to this variability of chemical composition certain forms of galvanic action are set up, giving rise to more or less rapid corrosion, and to the destructive effect known as "pitting."

As a general rule, looking to the differences in the mode of manufacture, wrought iron should in theory be more uniform in composition than steel, and it is thus less exposed to the above danger. Thoroughly homogeneous steel, i.e. steel perfectly prepared, is probably quite as free from corrodibility as the wrought iron in general use, but it would appear from the results of numerous tests that certain qualities of steel are more liable to corrosion in sea-water than wrought iron.[2]

A series of experiments to which much weight has been attached proved that acid and basic steel plates, when exposed to air, fresh water, and salt solutions gave almost precisely similar results. Another set of

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[1] Minutes of Proceedings Inst. C.E., vol. cxcix, p. 133.

[2] Journal of West of Scotland Iron and Steel Institute, 1907, vol. 14, p. 82. See Frazer.

experiments, in which plates of wrought iron and steel were subjected to prolonged exposure to air, salt water, and bilge water indicated that, taking the corrodibility of wrought iron at 100, the relative corrodibility of steel was equal to 133.[1] Very similar tests carried out in America in 1908 go to prove, however, that the behaviour of wrought iron and steel, when exposed to the action of sea-water, shows very little difference. This opinion is also shared by the engineers of some of the chief Steam Boiler Associations, who find that boilers of steel and wrought iron behave the same under similar conditions. The opinions of a number of manufacturers, when sought on this question, showed that, in the matter of practical use, the advantage of wrought iron over steel is very trifling. It is really mainly from the point of view of electrolytic action that steel suffers in comparison with wrought iron.

[1] Journal of Iron and Steel Institute, 1881, vol. i, p. 39.

THE VALUE OF TIMBER AS A MATERIAL FOR MARINE STRUCTURES.

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INCORPORATING

ADDITIONAL BOTANICAL OBSERVATIONS AND NOTES.

By F. T. BROOKS, M.A.

I. GENERAL CONSIDERATIONS.

Timber is used in a large number of structures erected on sea coasts, and it is the object of this report to compare the advantages of the various commercial timbers. The chief basis of comparison will be the powers possessed by different timbers to resist the deleterious actions which they are called upon to encounter by reason of their total, varying or occasional immersion in salt water. When wholly immersed, timber suffers little from the action of the salt water, but it may be seriously damaged through erosion by shingle, when set in motion by wave action and tidal currents, or it may be totally destroyed by marine organisms.

No fungoid organisms are known to exist in the sea which are able to penetrate and disintegrate submerged timber. It is also entirely exceptional for the parts of piles not exposed to sea action to become attacked by any form of "dry-rot," due to timber-destroying fungi, partly on account of the wood in these structures being either creosoted, or being of a kind very resistant to the attacks of fungi. The free circulation of air in these exposed situations and the action of the salt spray are also inimical to the development of fungoid growths, which, as is well known, are of serious importance in other kinds of structural work where efficient ventilation is difficult to obtain.

The ends of piles embedded in the sea bottom sometimes decay after a long time on account of the action of bacteria and other micro-organisms, but the length of life of marine piles is almost invariably determined by the teredo and other animal organisms long before this form of decay sets in.

It is not intended to deal with the inability of any timber to resist the actions of stress produced in the various members of the structures by wave-action or by superimposed loading. This is a highly important and necessary consideration, but it is beyond the scope of this article. It may, however, be noted that stress produced by wave-action is exceedingly difficult to estimate, little exact information being available, so that computations may be unreliable unless based on data obtained from experience extending over a considerable period in the vicinity of the proposed work.

II. SELECTION OF TIMBER AS A MATERIAL FOR CONSTRUCTION.

In the preparation of a design for any particular structure, an engineer has first to determine the materials which are to be used. Many important matters require consideration before he can arrive at a final decision; such as the climate of the locality and the presence of destructive organisms; the material, and degree of efficiency of skilled labour obtainable, and the consequent effect upon speed of construction; the strength, life and maintenance of the structure, and the prime cost.

It may safely be said that all ordinary building materials have been used in the construction of marine works, but probably by far the largest number of framed structures have been built mainly with timber.

Timber is grown and marketed in almost every part of the world, and may therefore usually be obtained commercially in any locality. This does not necessarily imply that highly efficient timber may be obtained at any place, but that there will be some timber available in most districts where a structure is likely to be erected. It thus often becomes a matter for decision whether it will pay an engineer better to utilize an inferior local timber rather than incur the additional cost to the structure of importing a more desirable wood. For portions of structures not readily renewable, as, for instance, under-water work, material would probably be imported, local timber possibly being incorporated in the remaining portions—that is to say, bracing, waling or deck, situated above low-water mark. It can, however, readily be seen that there are very few localities where it would be impracticable to employ timber for the erection of a marine structure.

An important feature in the use of timber is that labour, skilled in its handling and working, is generally available; whereas similar skilled labour for the working of steel, iron or reinforced concrete cannot be so readily obtained. In constructions of steel and iron (either wrought or cast) a very large amount of the work is carried out in the manufacturers' yards, and any required modifications have to be effected locally by skilled labour and the employment of some machinery. This consideration is important, as it is not always possible to erect marine structures with a high degree of accuracy, and minor variations from original dimensions frequently occur, and thus considerable delay is incurred if new parts have to be obtained from the original manufacturer or from some local firm. Difficulties of this type do not arise with timber, for the whole of

the work of construction is generally carried out *in situ*, materials not being supplied bored or cut to dead lengths. The same advantages can be claimed for reinforced concrete, the most important part of the skilled labour being employed upon the carpentry and joinery in the construction of the necessary shuttering; but it must not be forgotten that the knowledge of this special work is not yet very widely distributed, and, furthermore, that the labour used in fixing the steel reinforcement and the placing of concrete cannot be considered unskilled, and requires the most careful supervision.

The maintenance of a structure has a most important bearing upon the ultimate cost as well as upon its life and utility; from this point of view suitably selected timber has very great advantages, for it may be safely left with little or no attention for very long periods. The same claims are made for reinforced concrete, but in the case of steel or iron work, considerable and regular attention to the preservation of structures in these materials is essential, protective coverings have to be applied to prevent undue deterioration from rust, and the efficient application of such coatings is an exceedingly difficult matter, while in many situations it becomes practically impossible. Reinforced concrete usually requires no preservative coatings, but danger may occur through the accidental chipping away of the surface or the undue porosity of the concrete.

The maintenance cost of timber structures is likely to be high only in those districts infested by destructive marine organisms; naturally these animals do not affect iron or concrete, but they may render the reconstruction of unsuitable timber work a matter of necessity after a very short lease of life, and the damage may not be detected sufficiently early to avoid disaster. However, by the selection of a timber having adequate powers of resisting the action of these pests, the expense of maintenance can be very greatly reduced, and although the cost of the more suitable material may appear to be high, the benefits thus derived may so reduce the cost of maintenance as to make its use a favourable proposition economically.

Marine structures in which timber is chiefly used possess a great advantage in the elastic qualities of this material, which enable them to resist casual stresses produced by impact from floating articles, such as wreckage or the bumping of vessels.

Structures of the type under consideration are almost invariably carried upon pile foundations, and for this purpose timber is a very desirable material. The piles can be driven to considerable depths into the ground without damage, and being obtainable in single logs of very great lengths, extending in exceptional circumstances up to about 120 feet, it is possible to arrange for the timber forming the foundation to be carried through without a joint, so as to constitute one of the chief framing members of the complete structure.

Piles should be straight grained, free from loose or large knots, and the logs themselves should be perfectly straight. In many timbers, such, for instance, as hewn Greenheart logs, it is hardly ever possible under ordinary commercial conditions to avoid a certain amount of waney edge, but this does not affect the strength of the pile, though it interferes

considerably with the proper and efficient fitting of walings or bracings; for this reason it is undoubtedly an advantage to have a pile without waney edges, but in many instances this would necessitate the cutting away of a large amount of valuable material.

In certain cases piles are made from whole trees—that is to say, without any squaring or sawing. It is claimed that, in this form, they resist the marine borers or other destructive agents more effectually than squared or sawn piles. In Australia "whole tree" piles are commonly employed.

III.—THE STRUCTURE OF TIMBER.

Commercial timber is the wood or xylem of various kinds of trees, the functions of which in the living plant are to carry up to the foliage the ascending stream of sap, or transpiration current as it is sometimes called, and to give rigidity, so that the weight of the branches can be supported and the tree be enabled to resist the lateral stress of the wind.

In the living tree the wood is surrounded by a narrow zone of bark, the inner part of which conducts downwards to various parts of the tree the food materials elaborated by the green leaves from the carbon dioxide of the atmosphere, and the mineral substances brought up in solution from the soil by means of the transpiration current. The outer part of the bark consists chiefly of corky material and is essentially protective in function.

Situated between the bark and the wood of a growing tree is a layer of delicate cells, the cambium, which by division gives rise to new wood within and to fresh material (phloem) on the outside; this latter becomes part of the bark.

Like all other plant tissues, wood consists of minute cells, the organization of which can only be fully made out with the aid of a microscope. Even to the naked eye, however, it is evident that in a piece of oak wood, for example, not all the cells of the wood are alike. Some are minute pores obviously hollow—these are the vessels or water-conducting channels up which the transpiration current passes to the leaves. Other cells have much thicker walls and are of the nature of fibres to give strength. Finally, there are the cells which in young wood store up reserve food substances, such as starch, when the tree is not actively growing.

But much more conspicuous than the individual cells of which the wood is composed are the rings which form by far the most prominent feature of the "grain" of commercial timber. If the trunk of a tree is cut off horizontally, the exposed surface of the wood shows a number of concentrically arranged zones called annual rings, because usually not more than one is formed each year, and according to the manner in which the timber is cut so does the grain run. These rings are formed because the wood produced by the cambium in the early part of a season's growth is different in texture from that produced later, and so there is a regular alternation between spring aud summer wood. Traversing the rings of wood irregularly at right angles are the medullary rays, also formed by the cambium, the function of which in the tree is to store up food

reserves in the young wood, and to enable these to be transferred laterally in the tissues. In most timbers these medullary rays are quite inconspicuous, but in the oak they are so prominent as to be spoken of as the "silver grain."

In a mature tree the central part of the wood, or heart wood, is usually darker in appearance than the outer part, or sap wood; and in some kinds of trees the difference between heart and sap wood is remarkable. Heart wood no longer carries the stream of water upwards in the living tree, but functions solely as strengthening material. The darker colour of heart wood is due to the impregnation of the cells with chemical substances which tend to exert a preservative influence, hence in structural work it is more resistant to decay than sap wood. As its name implies, the sap wood carries up to the leaves the raw sap or transpiration current, but it ceases to function in this capacity after some years, and becomes gradually converted into heart wood.

The knots seen in timber are in reality the extremities of branches still embedded in the wood of the trunk.

Each kind of tree has a structure which in detail is peculiar to itself. Generally speaking the differences in appearance and texture of the commoner commercial classes of timber are so considerable that there is no difficulty in establishing the identity of the timber used for any particular purpose.

Timber is divided commercially into soft and hard woods. The former are derived from coniferous trees, such as the fir and pine; and as their grain is of a more uniform nature they are more easy to work than hard woods, such as oak and teak.

IV. SEASONING OF TIMBER.

Seasoning timber is generally supposed to be simply drying it; there is, however, a wet process or water seasoning. But the term implies more than mere drying or soaking, as chemical changes take place in the wood which render it less liable to fungus attacks, and efficient seasoning prevents further shrinking or warping. The strength of many woods is very much increased by seasoning.

Air Seasoning.—The timber is stacked with air spaces on all surfaces. It should be subjected to the action of cool dry air passing through these spaces, and it should be placed in the shade under cover. The length of time required for this process depends upon the nature of the timber and its size. If sun and rain are allowed to have access to the timber, the seasoning process is rendered irregular, and is not so satisfactory, as shakes are likely to develop.

Kiln Drying or Hot Air Seasoning.—By partially seasoning it in the open air before drying it in a kiln, the liability of the timber to split or shake, which occurs mostly in the early stages of artificial seasoning, is considerably reduced. Timber is heated up to about 200° F. during this process without suffering from loss of strength, but higher temperatures are apt to cause weakness in the timber. Rapid kiln drying tends to the

case-hardening of hard woods, and this produces extensive splitting in the interior of the log.

Steam Seasoning has somewhat similar effects to that of hot air kiln drying, and the same may also be said of boiling the timber in water; this latter method is expensive and leads to weakening of the wood.

Water Seasoning is a slow process, and necessitates total immersion to prevent fungoid growth at the water line, but good results are obtained in timber that is to be used in water or damp localities. A preliminary treatment by this process is advantageous to timber which is to be subsequently air seasoned. Salt water is said to have beneficial effects upon timber, rendering it harder and more durable.

Smoke Seasoning.—Timber dried by being subjected to the action of hot products from the combustion of fuel, has proved efficient, and this process has a preservative effect.

Oil Seasoning.—Boiling in oil or applying boiling oil to timber produces good results, but is very expensive.

Ring Barking.—Many timbers, more particularly hard woods, such as Teak and the Australian Eucalypts, have a ring of the bark cut away, when the trees are marked down for felling, and they are left in this condition for various periods up to three years before being actually cut. This has the effect of preventing the food substances made in the leaves from passing down to the roots. The underground parts of the tree are thereby starved, and as the root system ceases to absorb water the tree is killed; moreover, partial desiccation and seasoning of the wood ensues.

V. PRESERVATION AND PROTECTION OF TIMBER.

The life of a timber structure depends largely upon the selection of the most suitable wood, and upon the amount of additional artificial protection afforded to it. Generally speaking, the hard woods offer the greatest resistance to the various destructive agencies, and are therefore the most lasting, though some hard woods are readily attacked by "worms."

Below water the chief enemies to the long life of a structure are almost invariably the different kinds of marine borers. These organisms can and do attack every timber which is commercially available for constructive purposes, though many timbers have either great powers of resistance or are offensive to the borer. No timber is completely immune from attack, but several preventive means have been adopted with varying degrees of success.

Piles have been protected by sheeting them with metal such as zinc, copper or Muntz metal, and this method is in some degree efficient until the metal corrodes or the joints fail. Another expedient is to drive flat-headed or "scupper" nails into the timber so that the surface is practically covered; it is claimed that the rust which is produced thereby spreads over the whole surface and forms an effective protection from external attacks by the borers. Cement or concrete has also been used as a protective sheathing; in this case a concrete casing formed in halves is placed round the pile, or the material is deposited inside a mould placed at some few inches from

the timber. An interesting method of protecting a structure condemned by reason of the weakness of the piles is to encase the damaged piles with wire mesh and to apply a cement mortar by means of a cement gun; this method is applicable only where the whole of the pile is exposed at low water. Parts of a marine structure can be coated with coal tar or pitch, and wrapped with a similarly-coated textile material.

Creosote is used to impregnate timber, acting as a deterrent to the borer, but in order to obtain good results, the softer kinds of timber must be used, and to ensure that the material thus treated may acquire a high resistance a relatively large quantity of creosote per cubic foot must be injected. Where the attacks of marine pests are very active, as much as 12 to 14 lbs. per cubic foot must be injected into the timber; but when the highest form of resistance is not necessary, 10 lbs. may be used with fairly satisfactory results in home waters where the worm is not so active. It will be easily realised that the injection of an additional 4 lbs. per cubic foot above the normal quantity will render the treatment difficult and requires careful attention and supervision.

Above the water level, the harder kinds of timber are very prone to develop considerable cracks or "shakes" due to uneven seasoning of the wood. The strength is not seriously affected by these cracks, but their extension can be avoided by clamping, or applying iron bands, if the cracks are considerable.

VI. EFFECT OF MARINE BORERS.

Marine borers are exceedingly destructive to timber in certain localities, and it may be said that they are present in varying degrees in all salt water. Steps, therefore, have to be taken to counteract their action by various methods of preserving the timber, or by the selection of timbers most resistent to their ravages.

In many recorded cases the piles attacked by these animals are honeycombed to such an extent as to render them in a comparatively short time unsuitable to withstand the load they are designed to carry. The Limnoria will work across the grain, and usually affects the surface of the timber without penetrating to a great extent into the heart wood, except after a considerable time and when the surface layers first attacked have become disintegrated and eroded; the Teredo, however, enters through the surface and bores along the grain of the timber without producing external evidence of its action; the presence and extent of the consequent damage is, therefore, very difficult to ascertain.

The borers are frequently called "ship-worms" or "teredos," the best known being the *Teredo navalis* and *Limnoria lignorum*. Different kinds of wood have varying powers of resisting these borers; hardness alone is not a sufficient protection to a wood, but it is beneficial. Greenheart owes its power of resistance to its contents in alkaloids, especially bebeerine, and certain oils and acids help to protect the Eucalypts. The relative values of their powers of resisting borers are discussed under the descriptions of the various timbers.[1]

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[1] See also Paper by Dr. Calman, p. 63.

VII. GEOGRAPHICAL DISTRIBUTION OF TIMBER USEFUL FOR MARINE WORKS.

Forests occur in all parts of the world, except in desert regions and in tracts of country like the pampas of South America and the veldt of South Africa, where grasses are the dominant form of vegetation. The character of the forests of the temperate and subarctic zones is markedly different from that of the tropics. In the former climate the forests contain only a few kinds of tree, sometimes only one; whereas in tropical forests, with few exceptions, the diversity of species is immense. Large tracts of Northern Europe are covered by the Scots Pine (*Pinus sylvestris*), which is present to the exclusion of practically every other kind of tree, but in the teak forests of India the teak trees are generally present only as units amongst many other kinds. The difficulty of timber exploitation in the tropics is therefore much greater than in temperate regions, for in the one case large numbers of the same kind of valuable trees are aggregated together, whereas in the tropics the trees valuable for timber are usually found with a great number of others which are commercially worthless.

Trees of value for timber are of two kinds: those belonging to the cone-bearing group of plants, such as the Pine and Fir, and those such as the Oak, Greenheart, etc., belonging to the class of flowering plants known as Dicotyledons, these latter being usually referred to as the broad-leaved trees.

The conifers or soft woods are not generally found in the tropics except on mountains, and their chief centres of distribution are in the sub-arctic and temperate zones of the northern hemisphere, and in New Zealand. The broad-leaved trees or hard woods, on the other hand, flourish both in the tropics and in the temperate regions.

Some trees have a wide range of distribution, e.g. the Scots Pine, whereas others, e.g. Karri and Greenheart, are found only in relatively limited areas.

The risk of exhausting the supply of some of the more valuable kinds of timber trees is by no means negligible, and a future famine of this kind can only be averted by the scientific conservation of forest areas on a much larger scale than is at present practised.

Europe.

Very large quantities of useful timber are found in Northern Europe, principally Pines and Spruce, which are exported from Baltic and White Sea ports. Extensive forest areas of other kinds of coniferous timber are also found in Southern and Central Europe.

For ordinary marine construction the most widely employed timbers are Pine and Fir from the countries around the Baltic. These timbers are soft and in their natural state offer very little resistance to the ship worm, but when properly creosoted they are reasonably satisfactory in some localities.

Asia.

There are very extensive forests areas in Asia, but many of them are either impossible to develop at present or have so seriously suffered from cutting as to render the timber unsuitable for export, even if satisfactory means of transport existed.

In Siberia there are vast forests of Pine and Spruce, at present undeveloped through lack of transport facilities.

Japan is well wooded, but the supplies are largely required for local use, and there is very little export trade.

The forests of India contain very valuable trees; of these Teak, Acle and Sal are used extensively for marine work.

Borneo produces several very hard woods which possess limited powers of resistance to the marine pests, such as Billian, Ballow, Rassak, Tampinnis and Camphor. Other somewhat similar timbers are likewise available from the neighbouring Dutch Islands, and Acle and Tampinnis come also from the Malay States.

Africa.

Although there are vast areas known to be well timbered, up to the present time no appreciable development of these resources has been attempted.

Certain timbers have been exported from West Africa, such as Oak, Rosewood and Mahogany; but these have not been used to any extent in marine work. Considerable development is necessary before any large export can be expected, though many districts, when more thoroughly explored, may afford serviceable timbers.

North America.

Vast forests cover many areas in the North American Continent, both in the United States and Canada. In both these countries timber has been regarded in the past as so plentiful that it has not been properly tended, and consequently large quantities have been wasted. Extensive clearings have been made, and forest fires have consumed timber in many areas, but little or no thought has been given to replacement. Many good timbers have been used for fuel, while in the case of the useful Long-leaf and Loblolly Pines the abstraction of turpentine has sometimes been carried on without any regard for the subsequent fate of the trees. Both in the United States and in Canada recent warnings as to future shortages of timber have had the effect of inducing more care and regard for the forest areas.

The most useful timbers produced in the Northern Continent are Pines and Spruces, notably the White and Yellow Pine, Long Leaf and Loblolly Pine. In British Columbia and in the neighbouring part of the United States there is a very useful tree known as the Douglas Fir, or Oregon Pine, of which there are large quantities.

In addition to the main timbered portion of Canada which extends also through the States, there is a large undeveloped forest belt of considerable width, but consisting of comparatively small trees, stretching from Alaska to Belle Isle.

For the purpose of marine structures, the most useful timbers are the Oregon, Long Leaf, and White Pine ; none of these are able to resist the action of the marine borers when untreated, but they may be improved by creosoting, especially the Oregon and White Pines.

South America.

Large forests are found in the tropical and south-western parts of the South American Continent, and though no proportionate export trade is carried on an increasing amount of timber is being exported from Argentine and Brazilian ports.

The absence of effective railway transport from the forests to the sea coasts has materially interfered with export. In Brazil a very large variety of trees are known to exist, which of late years have been brought before the public by means of the Exhibitions, notably that held at Chicago, but the only timbers exported to any considerable extent are Mahogany, Logwood, Rosewood, and Brazilwood, none of which are utilised for marine structures.

Several heavy and close grained timbers are obtained from British Guiana and the West Indian Islands. In the British Guiana districts transportation of timber from the forests to the shipping ports is very difficult, and methods are primitive. Large quantities of timber are left uncut in forests not adjacent to the rivers, providing the means of transport to the coast. By recent railway development many forests have been opened up, and timber not previously marketable is now available.

Among the more important of the timbers grown in these regions, Greenheart, Mora and Wallaba may be mentioned. Of these, Greenheart is recognised as probably the best type of wood for employment in districts where the marine borers are known to be active.

It would appear from a paper contributed by Mr. L. M. Hill, B.E., M.Inst.C.E., to the Proceedings of the Institution of Civil Engineers, that besides Greenheart, British Guiana is capable of supplying valuable timber from the Bullet tree (*Mimusops balata*). This wood is very close-grained and dark red in colour. It can be obtained in logs up to 50 feet in length and 2 feet to 3 feet square.

Mora (*Dimorphandra mora*) is another close-grained wood which is exceedingly tough and difficult to split or saw. It is largely used locally for boat building, and can be obtained in logs of over 100 feet in length and $1\frac{1}{2}$ to 2 feet square.

The neighbouring States of Ecuador, Venezuela and Colombia have also large undeveloped timbered areas. Mora is exported from Honduras and Trinidad.

The most important timber from South America, for the purpose of marine construction work, is Greenheart, from British Guiana.

Australasia.

Australasia is well wooded in parts, and the continent possesses many timbers very valuable for the purposes of marine construction.

[1] Minutes of Proceedings Inst.C.E., vol. cxlvii., p 341.

Australian timber may be divided into two classes, one found on the western side of the continent, and the other in the east, the majority in both districts being Eucalypts.

Of the timber found on the western side of the continent, the following may be regarded as a fairly representative list:—Jarrah, Karri, Blackbutt, Red Gum, Wandoo, Tuart, York Gum, all of which are Eucalypts.

Of these timbers, Jarrah, Karri, Blackbutt and Red Gum have straight and even fibres, and are of moderate hardness and density, while Wandoo, Tuart and York Gum possess a closely twisted and interwoven grain, and are in general very hard and heavy. For the purposes of marine construction Jarrah is the most important and useful.

It is difficult for anyone not accustomed to inspecting samples of Jarrah and Karri to distinguish the one from the other. The following test can be readily applied, and may be of interest. A splinter struck from Jarrah and placed in a flame generally burns to a firm black ash, while one severed from Karri burns to a white woolly ash; also when the flame is blown out the Karri splinter glows for some little time, but the Jarrah splinter will go out immediately. The difficulty of distinguishing between Jarrah and Karri exists only in the case of the timber when cut, for in the forest the distinction is very clear and marked; Jarrah has a rough, broken, deep-coloured bark, and Karri has a smooth, clean, light-coloured bark not broken. The living trees differ, moreover, considerably in other respects.

An additional test has been laid before the Committee, and is reported to give satisfactory results. The outer surface of a log to be tested should be removed with a sharp knife or chisel, and within a period of three or four minutes a drop of caustic soda solution of a specific gravity of 1·2 should be applied to the clean surface by means of a glass rod. In the case of Jarrah a black spot will form under the solution almost immediately, but with Karri a brown spot will be formed which will darken slowly.

The eastern side of the Australian Continent produces a different range of timbers, of which the following is a concise and representative list: Ironbark, white or grey, narrow and broad leaf; Stringy Bark, red; Tallow wood and Murray Red Gum. To these, which are Eucalypts, may be added Turpentine wood, which is fairly resistant to the action of marine organisms.

The varieties of Eucalypts in the East are very numerous, but for marine construction work they are not so suitable as those found in the western areas. Turpentine wood has been largely used for piles in such works as wharves and piers, particularly in the Sydney district.

Tasmania has very extensive forest lands, approximately one-half of the island being timbered. The most valuable timber is the Blue Gum, of which considerable quantities are found around Hobart, and in the south of the Island. Another very important timber, and scarcely to be distinguished from the true Blue Gum, is the Tasmanian Stringy Bark, of which latter the available supply is also larger. Huon Pine is a highly

durable and much valued timber, but it is now very scarce. Other timbers are Peppermint, Swamp Gum and Ironbark.

New Zealand has considerable resources in timber, the most important kinds being the coniferous Totara and Kauri Pine.

VIII.—PARTICULARS OF VARIOUS TIMBERS AND TREES USED IN ENGINEERING WORKS.

Europe.

Scots or Northern Pine is widely distributed over the whole of Northern Europe, and is exported principally from the Baltic Sea, White Sea, Norwegian and Swedish ports; it is usually classified by means of the port from which it is shipped. The height of the tree is about 100 feet; it ranges about 2 to 4 feet in diameter; the weight of the wood varies according to locality and rate of growth.

This timber is known as Baltic Fir or Redwood when exported from such ports as Memel and Dantzig. The description as Fir is commonly accepted, but it is a misnomer, as the timber is a Pine.

When shipped from Memel the timber is classified as:—

Best Middling,
Second Middling,
Bauholz.

Shipped from Dantzig the classification is:—

Best Middling,
Good Middling,
Common Middling.

Of these classes of timber the second quality is that which is most frequently used for piling, Dantzig ("Good Middling") is usually of rather better quality than Memel ("Second Middling"). Common Middling is of doubtful utility, as it frequently contains large knots, while Memel Bauholz may also contain defective knots. The first quality of either type is usually free from knots, and is inclined to be sappy; it is also considered to be not so durable as the second qualities.

The exported timbers vary in length from 18 feet to 40 feet, and in section from 12 to 15 inches square, but they usually average about 25 or 26 feet long by 13 inches square.

This timber should be creosoted if it has to resist marine destructive agencies.

Common Spruce, found as widely distributed as Northern Pine, grows loftier than that timber, the height reaching about 140 feet, while the diameter attains a maximum of about 4 feet 6 inches. Spruce is not used to any extent in marine construction. It is largely imported from Norway for scaffold poles and pit props. Its weight when seasoned is about 30 lbs. per cubic foot.

Larch reaches to a height of about 120 feet, with a weight when seasoned of about 35 lbs. per cubic foot. It is not generally used for piling work unless entirely submerged. It has been used to a very great extent for pile foundations in Venice.

Oak grows to a maximum height of about 100 feet, with greatly varying diameters. Its employment for piling work is not usually a commercial proposition.

Elm attains a height of about 85 feet, with a diameter of 2 to 3 feet; its shows considerable variation in the weight of a cubic foot. The wood is tough, durable and elastic. It is interesting to note that the Rialto at Venice is said to be built on Elm piles, but no extensive use is now made of Elm for this purpose.

Asia.

Sal is found in Northern and Central India, growing to a height of about 130 feet, with diameters up to 6 or 8 feet. It is heavy, hard and coarse grained. Logs up to 60 feet can be obtained, about 18 inches in diameter. It is used in Northern India for piling. The weight is about 55 lbs. per cubic foot when seasoned.

Acle is found in India, Burmah, the Malay Peninsula and the Philippines. It grows to a height of about 100 feet, and yields timber up to about 2 feet square. The timber is brown in colour, hard, tough, stringy and heavy, the grain is, however, often twisted. The weight is about 60 to 65 lbs. per cubic foot when seasoned.

Ironwoods of various kinds are found in the East India Islands and surrounding countries. Billian weighs about 70 lbs. per cubic foot, Ballow and Tampinnis about 67 lbs. per cubic foot when seasoned. All these trees are cut when very large, and produce timber which is said to be suitable for use in structures which the marine borers are likely to attack. Experience, however, has shown that in certain circumstances the life is extremely limited. Billian is considered the best local timber in the East Indian districts, but it is somewhat difficult to obtain. Ballow makes a good substitute. Rassak and Cheam are also useful timbers, though they do not possess the same lasting qualities in sea-water as Billian or Ballow. These timbers can be obtained in logs up to 40 feet in length and up to 24 inches square in section.

Teak is distributed over a wide area of Southern Asia, including Burmah, Siam, the Malay Peninsula, the Dutch East Indies, Central and Southern India.

The wood varies in colour from yellow to brown, and becomes darker when it is seasoned. It is moderately hard and strong, clean, even and fairly straight in the grain. It works easily, does not shrink much in seasoning, and after this has been effected, it does not warp. There are no shakes on the outer surfaces of the log, but heart-shake is frequently encountered. A resinous oil clogs the pores, and resists the action of water. The locality in which the timber is grown affects the quality very greatly; the timber grown in Burmah and Siam is the finest and largest; trees being found 100 feet or more in height, with a diameter up to 8 feet. Logs can be obtained from these trees up to 50 feet in length, and 30 inches square in section. The weight of the wood varies between 60 lbs. per cubic foot unseasoned, down to about 40 lbs. seasoned.

Teak wood is said to be efficient in some localities in its resistance to marine action and organisms, and it has been most extensively used in

the construction of ships. Its most important property lies in the ease with which it can be wrought, and its non-liability to warping. Many so-called "Teak" timbers are not true Teaks, though useful materials, for instance, Johore Teak (now rare), African and Bastard Teak.

Long timber is not plentiful in Penang and is at times very difficult to procure; it is obtained from Sumatra, the Dindings and Siam. Merabu and Chengi are the two first-class hard woods, similar to the Singapore Ballow.

The standard length for this timber is usually about 16 to 24 feet. For timber 35 to 45 feet in length the rate would be liable to be very considerably increased.

Duma laut is also a first-class hard timber; the price ruling for this is the same as Merabu and Chengi, but it is of no use for piles over 24 feet long, as it is very seldom that a straight log can be procured.

Dama menick is a timber that is very similar to the Dac Ballow of Singapore, and in standard lengths of 16 to 24 feet it can be procured without much difficulty. For logs 35 to 45 feet long the rates are very much higher.

Bakaw Roller timber for piles can at the present time be procured 4 to 6 inches diameter, up to 16 feet long. If the timber is required over 20 feet long, the rates per pile are more than doubled.

North America.

Pitch Pine[1] is the description usually applied to the Long-Leaf Pine, found largely in the southern districts of the United States, and shipped from southern ports of that country. The tree grows to a height of 75 to 100 feet, and varies in diameter up to 4 feet. The wood has a reddish colour and is more resinous than the common Northern Pine of Europe; it is also heavier. Turpentine is obtained from the Long-Leafed Pine trees, and as a result large quantities of these trees are impoverished by "bleeding" or by the careless extraction of resin. Pitch Pine is exported in sawn wood, in lengths varying between 12 and 55 feet, with a sectional area of 6 to 12 inches square; hewn logs vary from 20 to 70 or 80 feet in length, and from 9 inches to 27 inches square in section. The weight is 40 to 45 lbs. per cubic foot when seasoned.

Long lengths of this sawn timber are termed "special" in the trade; that is to say, logs of 45 feet long and upwards by, on an average, 12 inches square in section. This class of timber is getting short, and hewn logs also are not plentiful.

Pitch Pine piles drive well and take a lot of "punishment" in the process before showing any signs of failure. They have often to be selected on account of the greater lengths in which they can be obtained, in conjunction with their comparatively low cost.

The lasting powers of Pitch Pine are very variable, and consequently opinions as to its durability can be formed only from experience. It affords little resistance to the marine borer, but it may be somewhat

[1] Timber imported into this country under the name of Pitch Pine is usually the Long-Leaf Pine (*Pinus palustris*), but in the United States, *Pinus rigida*, which gives a less useful timber, is generally spoken of as Pitch Pine.

improved in this respect by creosoting, though it is difficult to get more than about 4 to 5 lbs of creosote into a cubic foot.

Oregon Pine or Douglas Fir is found on the north-western side of the North American Continent, the larger forests being in the Californian and British Columbia regions. The timber is exported from Victoria, Vancouver and the Fraser River, B.C., also from the Puget Sound ports.

Large numbers of the trees are to be found growing to a height of 250 feet, and several grow as high as 300 feet, the diameter ranging up to 12 feet. Logs are exported in lengths from 12 to 100 feet and over, they vary from 4 inches to 32 inches square in section. There is said to be an unlimited quantity of timber 40 feet to 80 feet long by 12 to 20 inches square in section. The ring of sapwood is narrow, the general colour is yellowish; the timber is coarse but straight-grained, quick growing, and the annual rings are well defined.

Oregon Pine compares favourably with the rest of the pines for durability, but it possesses their failings, in that the "teredo" will readily attack it. The weight of Oregon Pine when seasoned is 35 to 40 lbs. per cubic foot.

Elm (Canadian) is a wood having special properties of hardness and toughness. It is heavy and very compact. Logs are exported which vary from 20 to 40 feet in length. The timber is durable under water, and is used to a considerable extent for fenders in marine works. The weight when seasoned is about 45 lbs. per cubic foot.

Other Firs, Pines and Spruce, e.g. *Redwood, Loblolly Pine, White Pine, Spruce White and Black,* and various other allied trees, are found distributed to a very large extent over the Northern American Continent. The value of the forests has been greatly reduced by lack of conservation, while careless tending has resulted in huge forest fires. These Firs and Pines are all soft woods, and have little power of resistance to weather, sea and the teredo.

South America.

Greenheart is found in the northern section of the South American Continent, but it is being cut in marketable quantities only in British Guiana near the Essequibo, Demerara and Berbice Rivers; it is not found on high ground, but grows usually in districts not greatly above sea level.

The tree is of considerable size, ranging from 60 to 100 feet in height, and from 2 to 4 feet in diameter. Good straight logs can be obtained, but they rarely exceed 70 feet in length. The usual length is not much in excess of 50 feet. Logs can be obtained up to 18 to 20 inches square, but the more usual size may be considered as about 16 inches square; long logs generally taper considerably.

Greenheart belongs to the same family as the Bay Laurel and Sassafras, and is a very close and fairly straight-grained timber, having a large range of colour, grey, yellow, green, brown, and under certain conditions it is almost black. The colour will vary very considerably in the same tree. It is practically an evergreen, though fewer leaves are present during the dry season than in the wet. It has high powers of resisting the marine borers, on account, as already stated, of the presence

of an alkaloid, known as bebeerine, and owing to resinous in-growths into the pores of the wood known as tyloses, which tend to make the wood darker.

As the tyloses develop with the growth of the tree, the maturity of the timber may, to a certain extent, be gauged by its colour, although this partly depends upon the locality of growth. In general it can be stated that the darker coloured timber is the more durable.

Seasoned Greenheart weighs about 70 lbs. to the cubic foot.

It is found to be of great durability in structures constructed in water, and where the marine borers are likely to cause excessive damage. It has been very extensively used in pier and wharf construction, as also in dock gates, and has shown magnificent lasting quality. Greenheart employed in the original construction of dock gates for the Mersey Dock and Harbour Board in 1856 was used again in reconstruction in 1894. The sills and fenders for the Panama Canal Locks were constructed of Greenheart, as were also the lock gates of the Manchester Ship Canal.

Trouble is experienced with this timber as it is likely to split, and great care is necessary in seasoning and working; the cracks are usually found near the ends of the timber, and may be curtailed by binding the log; they do not as a rule extend for any great length. Greenheart, more especially in the younger trees, has a very great proportion of sap wood, which has not the same valuable properties as the sound timber for resisting deterioration in sea-water.

Several timbers have been sold as substitutes for genuine Greenheart, some of them come from the British Guiana forests, but the weight of such timbers is usually less, and the difference should be easily detected.

African trees of a hard and close grained nature have been marketed under the name of African Greenheart. There are also several trees of a different species found in the West Indies which are locally known as Greenheart.

Mora.—This is the loftiest tree of British Guiana and attains a height up to 200 feet; the wood is very tough, close and straight grained, and of a reddish-green colour; it is also heavy and hard. Mora is much less effective than Greenheart in resisting marine borers. Logs up to 100 feet by 18 to 24 inches square can be obtained. Its weight is from 60 to 70 lbs. per cubic foot when seasoned.

Wallaba is another timber found in British Guiana, and it also grows in Brazil. The wood is dark, and is saturated with a sticky resin; it is somewhat coarse in the grain. Logs up to about 50 feet by 12 to 18 inches square can be obtained. Its weight is from 50 to 60 lbs. per cubic foot when seasoned. Wallaba is not a very durable timber, and it is less suitable than Greenheart for marine work.

Australasia.

Western Australia.—*Jarrah* is found in the south-western district of Western Australia where there are large forests producing hardwoods, all of which are Eucalypts. The area in the colony that produces Jarrah wood in marketable form is about 8,000,000 acres in extent. Blackbutt and Red Gum are also found in this area. The Jarrah trees

are frequently found to attain a height of 90 to 120 feet, the stems are straight and true for practically the full height and no branches occur lower than about 50 feet from the ground; the average tree, however, may be considered as being 90 to 100 feet in height and 3 feet in diameter at the base. The trees grow to perfection in ironstone ranges, those growing on low-lying land being generally inferior in quality.

The wood is of a reddish colour, hard and dense, close and straight grained, with moderately interlocking fibres. It is resinous in character, secreting a highly pungent acid which is supposed to confer upon it the power of resisting attacks of sea-worms and insects. Jarrah weighs about 70 lbs. per cubic foot when first cut and becomes reduced to 55 or 60 lbs. per cubic foot in weight when seasoned.

Piles can be obtained in lengths up to about 55 feet by 14 inches square, and they may be driven without undue risk of splitting, provided that all ordinary precautions are taken.

Jarrah is considered to be one of the most suitable timbers for resisting the action of the marine borers, especially in home waters, where the teredo and limnoria are less active.

Karri is found in the same districts of Western Australia as Jarrah, but the area afforested with this timber is smaller.

The timber is slightly less red than Jarrah, being of a pale red hue; it is hard and heavy, and as the fibres are firmly interlaced it is a stronger timber than Jarrah. It contains tannin and gum resins.

The tree is of very fine growth, reaching, in the Warren River district, to a height of 300 feet, and in the case of large trees there are no branches lower than 180 feet from the ground, the diameter at the base being about 7 to 8 feet. It is thus possible to obtain long sound timbers from these trees, but Karri is not held in such high favour as Jarrah for its resistance to the attacks of teredo in marine construction. Logs of Karri have been obtained up to 100 feet in length and 20 inches square in section, but the more usual size is about 55 feet long by 14 to 15 inches square in section. It has, however, been largely used for walings, bracing and deck work, in which it has given useful results. The weight is about 62 lbs. per cubic foot when seasoned.

Blackbutt is found scattered among the Karri and Jarrah, and does not grow in separate forests. It reaches a height of 120 feet and a diameter of 6 feet, principally in the gullies of the Darling Range, and the best examples of its growth can be found in the valley of the Hamilton River in the Collie District. The timber is light in colour, hard, dense, and very tough. There is no considerable export, and it is used locally for piling work. Its weight is about 75 lbs. per cubic foot unseasoned, and about 55 lbs. seasoned.

Red Gum is widely distributed, and is of a handsome appearance having a height of about 100 feet, with a diameter of 3 feet; it grows in low lying country and loamy soil. The timber is much lighter than that of other West Australian Eucalypts, and it is intersected by large gum veins, rendering it unsuitable for permanent works.

Wandoo is widely distributed, but it is not found in great quantities. It grows generally in fairly open country to a height of from 80 to 120

feet, with diameters up to as much as 17 feet, but averaging about 3 feet. The wood is a light shade of brownish red, very hard, tough and durable, with weight per cubic foot when seasoned varying from 65 to 70 lbs.

Tuart is not plentiful, and it is found only in the coastal district between Fremantle and Russelton. It attains a maximum height of about 150 feet and a diameter of 8 feet. It is widely branched, and thus produces logs only up to about 45 feet long, varying between 12 and 24 inches square in section. It is a straight-growing wood of a light yellow or cream colour, and it is very hard, dense, and interlocked in grain. It is one of the heaviest known timbers, being as much as 70 lbs. per cubic foot when seasoned.

York Gum occupies a long tract of country several miles in width on the slopes of the Darling Range. The height of the tree does not usually exceed 80 feet nor the diameter 3 feet. It is a light pink in colour, exceedingly hard, heavy and tough, and weighs about 68 lbs. per cubic foot when seasoned.

Eastern Australia.—*Ironbarks* are found in New South Wales and Queensland. They vary in colour from pale cream to a dark red, and have all very much the same properties. They are widely distributed, and the supply is plentiful. The tree frequently attains a height of about 100 feet, and is often considerably higher, with diameters varying up to 5 feet. The wood is very hard, heavy, strong and straight grained, but it is liable to heart-shake. The weight of a cubic foot when seasoned is 65 to 70 lbs.

Stringy Bark Red (Forest Mahogany) is found in the north eastern districts, and grows to a height of 130 feet, with a diameter of 5 feet. The wood is variable in colour, ranging from light or dark brown to dark red; it is very heavy, close-grained and strong. This wood weighs about 65 lbs. per cubic foot when seasoned.

Tallow wood, which takes its name from its greasy nature when cut, is found in the coastal region of the eastern districts, and the supply is plentiful. It grows to a height of about 120 feet with a maximum diameter of 5 feet. The colour when freshly cut is light yellow, changing during seasoning to pale brown. It is strong, heavy and very durable. It is liable to shakes, and timber cut from large trees is often found to be hollow. The weight of a cubic foot is from 60 to 70 lbs., when seasoned.

Murray Red Gum is found in New South Wales, and is regarded as a very valuable and useful timber. It is widely distributed over the central and southern sections of the State, and the supply is plentiful. It grows to a height of 100 feet, with a diameter up to 6 or 8 feet. The weight of a cubic foot is about 60 lbs. when seasoned. It is of a dark red colour, exceedingly hard, particularly when dry. It is liable to shakes and warping during seasoning processes, and it is very durable.

Turpentine, which is not a Eucalypt, is found in the coastal district, and grows to a height of 150 feet, with a diameter of 5 feet as a maximum. The wood varies in colour, from brown to dull red, and is liable to shrink and warp unless well seasoned. The weight of a cubic foot is about 62 lbs. when seasoned. It possesses lasting properties when embedded in

damp ground, and it is very extensively used in Sydney for piles, as it has shown resistance to teredo attacks. The resisting power is supposed to be due to an oleo-resin, which is found principally between the timber and the bark. For this reason the best results in piling have been obtained from whole trees driven with the bark on.

TASMANIA.

Blue Gum derives its name from the bluey-grey appearance of the whole plant in the early stages of growth. It is found abundantly in the south-western districts of the island. The tree at full growth will average 7 feet diameter at the butt, while the lowest branch will be about 100 feet from the ground, and the height from 200 to 250 feet. In the sapling stage it grows very rapidly, but when maturity is reached the growth is hardly perceptible. The rate of growth is affected by locality, the quicker growth being made in good, deep, moist soil; rocky situations are not so favourable. The trunk is cylindrical, straight, and erect, and the wood is of a pale straw colour, hard, heavy, and tough. Hewn logs may be obtained up to 120 feet in length, and 20 inches square in section. Large quantities are available up to 75 feet long and 15 to 16 inches square in section. The wood is heavy, and weighs about 70 lbs. per cubic foot in the semi-seasoned condition in which it is used for piles. These therefore do not float in sea-water.

This timber is extensively used on important works; it was employed for instance as staging for the erection of the Admiralty Harbour Works at Dover, in which case piles used for erection work were drawn when no longer required and subsequently used in a permanent wharf. It was also used at Keyham Dockyards, and at many places on the East Coast. There is a tendency to split above water level from irregular seasoning.

Stringy Bark when cut is difficult to distinguish from Blue Gum, and, generally speaking, it is slightly inferior to that timber. It is freely distributed over the island in the coastal and semi-coastal districts, being found growing over large tracts of poor, hilly country. The average tree at maturity is of even greater height than Blue Gum. and often attains to 250 feet and 300 feet, with a diameter at the butt up to 10 feet. The wood has the appearance of oak, is light to dark brown in colour, hard, straight, and coarse in the grain, heavy and tough. It is liable to shakes and gum veins. Logs equal in size to those of Blue Gum can be obtained (120 feet × 20 inches × 20 inches), and the timber can be used with advantage for piling. The weight of a cubic foot of Stringy Bark is about 62 lbs. when seasoned, or very slightly lighter than sea water.

The Tasmanian Stringy Bark is of better quality than the same tree grown in Australia. This timber should not be confused with the Red Stringy Bark, though both are Eucalypts.

Huon Pine is so called because it was first found on the Huon River. It is a pine which grows to a great height on the West Coast, but it is now getting scarce. The maximum height is 100 feet, and it has a diameter at the base of as much as 6 feet. The wood is white, with very little sap, and it works easily, and is said to contain an essential oil which

acts as a protection against attacks from teredo. It is close grained, tough, and durable, but it has a somewhat short fracture. The weight of a cubic foot of Huon Pine is about 35 lbs. when seasoned. Most of the finest timber grows below flood level; it is thus an exception to the general rule that durable timber does not grow in swampy ground.

Peppermint, *Ironbark*, and *Swamp Gum* are Eucalypts, having similar properties to the Stringy Bark and Blue Gum, but hardly equal them for marine structural purposes, and they are not to any appreciable extent available commercially.

New Zealand.

Totara.—Known as the "New Zealand Yew," grows to a height of 120 feet, with a diameter up to 10 feet, yielding logs 45 feet long and up to 24 inches square in section. There is a wide sap wood of a light red colour, the heart wood being darker red. It is moderately hard and heavy, fine and even in the grain. The weight of a cubic foot is about 35 lbs. when seasoned.

Kauri, also known as "Cowdie Pine," is a valuable soft wood, weighing about 37 lbs. to the cubic foot when seasoned. It grows to a height of about 150 feet, with a diameter up to about 10 feet or more. It has wide sap wood, which is resinous; the heart wood is a pale brown in colour; it is straight in the grain, and is moderately hard. Kauri is a highly valuable timber for general purposes.

List of Timbers referred to in Report with their Botanical Descriptions and Locality of Growth.

Name.	Botanical Description.	Locality of Growth.
Acle	Xylia dolabriformus	India, Malay States
African Oak or Teak	Oldfieldia africana	Africa, West
African Mahogany	Meliaceae (order)	Africa, West
Ballow	Parinarium oblongifolium	East Indian Islands
Billian	Eusideroxylon zwageri	East Indian Islands
Blackbutt	Eucalyptus patens	Australia, Western
Blue Gum	Eucalyptus globulus	Tasmania
Camphor (Bornean)	Dryobalanops aromatica	Borneo and Sumatra
Cirouaballi	Nectandra (genus)	British Guiana
Douglas Fir	Pseudotsuga douglasii	California
Elm, Common or English	Ulmus campestris	Europe
Elm, Canadian	Ulmus racemosa	Canada
Fir	Abies and Picea (general)	Northern Hemisphere
Fir, Douglas	Pseudotsuga douglasii	California and British Columbia
Greenheart	Nectandra rodiœi	British Guiana
Gum, Blue	Eucalyptus globulus	Tasmania
Gum, Red	Eucalyptus colophylla	Australia, Western
Gum, Red, Murray	Eucalyptus rostrata	Australia, Eastern
Gum, Swamp	Eucalyptus regnans	Tasmania
Gum, York	Eucalyptus loxophleba	Australia, Western
Huon Pine	Dacrydium franklinii	Tasmania
Ironbark:—		
Broad leafed	Eucalyptus siderophloia	Australia, Eastern
Grey or White	Eucalyptus paniculata	Australia, Eastern
Narrow leafed	Eucalyptus crebra	Australia, Eastern
Tasmania	Eucalyptus sieberiana	Tasmania
Red	Eucalyptus sideroxylon	Australia, Eastern

Name.	Botanical Description.	Locality of Growth.
Ironwood :—		
(Ballow)	Parinarium oblongifolium	Borneo and South Indian Islands
Billian	Eusideroxylon zwageri .	Borneo and South Indian Islands
Jarrah	Eucalyptus marginata .	Australia, Western
Karri	Eucalyptus diversicolor .	Australia, Western
Kauri Pine	Agathis australis . . .	New Zealand
Larch	Larix europæa	Europe
Mahogany, African . .	Meliaceae (order) . . .	Africa, West
Mahogany, Forest (Stringy Bark Red)	Eucalyptus resinifera . .	Australia, Eastern
Mora	Dimorphandra mora . .	British Guiana and West Indies
Murray, Red Gum . .	Eucalyptus rostrata . .	Australia, Eastern
Oak, African (or Teak) .	Oldfieldia africana. . .	Africa, West
Oak (Common) . . .	Quercus robur. . . .	Europe
Oaks	Many varieties	All Continents
Oregon Pine	Pseudotsuga douglasii .	California and British Columbia
Peppermint.	Eucalyptus amygdalina .	Tasmania
Pine, Huon.	Dacrydium franklinii . .	Tasmania
Pine, Kauri	Agathis australis . . .	New Zealand
Pine, Loblolly	Pinus toeda.	North America
Pine, Longleaf . . .	Pinus palustris. . . .	Southern United States
Pine, Northern . . .	Pinus sylvestris . . .	Northern Europe
Pine, Oregon	Pseudotsuga douglasii .	California and British Columbia
Pine, Pitch	Pinus palustris (*See also* Pinus rigida, p. 54)	Southern United States
Pine, White	Pinus strobus	North America
Pines	Many other varieties . .	Northern Hemisphere
Rassak	Vatica rassak	Borneo
Red Gum	Eucalyptus colophylla .	Australia, Western
Red Gum, Murray . .	Eucalyptus rostrata . .	Australia, Eastern
Sal	Shorea robusta. . . .	India
Spruce, Common . . .	Picea excelsa	Northern Europe
Spruces	Many other varieties . .	Northern Hemisphere
Stringy Bark Red . . .	Eucalyptus resinifera . .	Australia, Eastern
Stringy Bark, Tasmanian	Eucalyptus obliqua . .	Tasmania
Swamp Gum	Eucalyptus regnans . .	Tasmania
Tallow Wood	Eucalyptus microcorys .	Australia, Eastern
Tampinnis	Sloetia sideroxylon . .	Borneo, Malay States
Teak.	Tectona grandis . . .	India, Siam, East Indies
Totara	Podocarpus totara . . .	New Zealand
Tuart	Eucalyptus gomphocephala	Australia, Western
Turpentine	Syncarpia laurifolia . .	Australia, Eastern
Wallaba	Eperna falcata	British Guiana and Central America
Wandoo	Eucalyptus redunca . .	Australia, Western
York Gum	Eucalyptus loxophleba .	Australia, Western

ON MARINE BORING ANIMALS.

By W. T. CALMAN, D.Sc., Assistant in the Department of Zoology, British Museum.

I. INTRODUCTION.

A general account of the marine animals destructive to timber has been given in the introduction to Mr. Redgrave's "Abstract of References in the Proceedings." The following notes are to be regarded as a supplement to this, dealing, from a zoological point of view, with some details that are, or may be, of importance to the engineer. For the guidance of those who may wish to pursue the subject further, references are given to some of the chief sources of information, and certain directions are indicated in which research is likely to be profitable. A few remarks have been added regarding the animals that bore into stone, since their destructive effects may occasionally call for the serious attention of the engineer.

A first essential in an enquiry of this kind is the precise determination of the species of animals concerned. The practical man is often apt to look upon this as a matter of merely academic interest, and to be satisfied with a rough indication that certain damage has been caused by *Teredo* or *Limnoria*. Even this indication may sometimes be strangely wide of the mark, as in the case of some specimens recently sent to the Natural History Museum as *Teredo*, and blamed for causing faults in a deep-sea telegraph cable. These specimens proved to be tube-dwelling worms of the family *Serpulidæ*, quite incapable of boring, and in all probability innocuous to the cable which their tubes encrusted.

It is by no means the case, however, that even the finer distinctions of the systematic zoologist can be pronounced to be without practical significance. We know that in some groups of animals species of the same genus, distinguished only by trifling differences of structure, may

differ widely in habits, in habitat, and in geographical distribution. The *Teredo* of the engineer may comprise, at its narrowest, some twenty to thirty different species. We know already that some of these differ from others as regards, for instance, the capability of surviving in brackish or even in fresh water, and it would be surprising if they were all found to react in the same way to the various means adopted for warding off their attacks.

II. ANIMALS BORING IN TIMBER.

While structures of timber on land suffer mainly from the attacks of fungi and of insects, these two groups of organisms are almost entirely absent from the sea, and the enemies of submerged timber belong exclusively, as far as is known,[1] to the animal kingdom and to the two groups of Mollusca and Crustacea. The Mollusca include the so-called "Ship-worms," known and dreaded by mariners from remote antiquity. The knowledge that Crustacea may be equally destructive is hardly more than a century old, and most of the species concerned have no popular names.

A.—The Ship-worms (*Teredo*).

The wood-boring Mollusca of importance to the engineer are practically all bivalves of the family Teredinidæ, and are commonly spoken of as "Teredo," although in systematic zoology they are not all ranked within the limits of the typical genus *Teredo*.

The first to show that *Teredo* belonged to the Mollusca was Godfrey Sellius (1733),[2] whose learned treatise on its natural history may be taken as the beginning of scientific investigation of the subject. The French naturalist Quatrefages (1849) greatly extended our knowledge of its structure, and gave the first account of its development and early larval stages. In 1858 the extensive damage caused by the shipworm in Holland led the Royal Academy of Science in Amsterdam to appoint a commission to investigate the subject. This commission published a series of reports (1860–69) containing much information on the natural history of the animal, and giving the results of a long series of experiments on the resisting powers of various timbers and on the methods of preventing damage. These reports are conveniently summarised in two articles by Baumhauer (1866 and 1869). Among many later papers, Hatschek's (1880) account of the early development of the *Teredo* may be mentioned, while Sigerfoos (1908) has more recently published an important monograph on the structure and life history of a species found on the American coast.

All the species are similar in general appearance and structure, although they differ greatly in size, full-grown specimens of *Teredo navalis*

[1] Some engineering writers refer to "decay" and even to "putrefaction" of timber exposed to the sea, independently of the attacks of boring animals. This decay is said especially to affect timber that is alternately covered by the tide and exposed to the air. I am not aware that its causation has been investigated.

[2] The numbers in parentheses after names of authors refer to the list of books and papers at the end of this report.

measuring 12 to 16 inches in length, while some of the forms found in tropical waters may reach a length of 4 and perhaps of 6 feet. When extracted from its burrow the animal, Fig. 1, is seen to have a long, soft, worm-like body, widest at its inner end, where it carries a pair of small shelly plates. These plates represent the two valves of the shell of a mussel or cockle, but while in these molluscs they enclose and protect the whole body of the animal, in the shipworms they are so reduced that only a small portion of the head region is covered by them. The valves have a peculiar and characteristic shape, Fig. 2, the front edge having a deep angular notch, and looking as if a piece of the shell had been broken away. Parallel with the edges of this notch the surface of the shell bears a series of very minute ridges and grooves. Under the microscope the ridges are seen to be rows of exceedingly fine teeth, like those of a file or rasp, and it is by means of these that the shipworm rasps away the wood to form its burrow. There has been much discussion as to the method of excavation, but there can be no reasonable doubt that the shell is the boring organ. The mechanism of its working has been clearly explained by Sigerfoos.

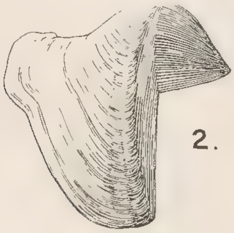
At the narrower end of the body, next to the opening of the burrow, are two slender tubes or siphons, of unequal length, which during life are protruded from the surface of the wood. Just at the base of the siphons on either side of the body is a pair of small shelly plates known as the "pallets," Fig. 3, which serve to block the opening of the burrow when the siphons are withdrawn, and so to prevent the entrance of enemies. These pallets differ much in shape and afford the readiest means of distinguishing several of the species. In the genus *Teredo* (in the restricted sense) they are paddle-shaped, with a slender handle which is embedded in the substance of the body. In the allied genus *Xylotrya* they are made up of a series of segments with a long stalk, and may look like a pair of quill feathers protruding from the surface of the wood.

When the siphons are extended a current of water is constantly flowing through them, entering by the longer and leaving by the shorter siphon. Internally the siphons open into two passages running almost the whole length of the body, and separated from each other by a partition formed by the gills. The gills have a lattice-like structure, and are covered with minute vibratile hairs or cilia, the movements of which maintain the circulation of the water. While the current of water serves the purpose of respiration, it also brings in numerous microscopic floating organisms on which the *Teredo* feeds. This, however, is not the only source of nourishment, for the fine "sawdust" produced by the rasping action of the shell is swallowed and passes through the stomach and intestine. There has been much dispute as to whether the *Teredo* actually feeds on the wood through which it burrows. That it swallows the wood is certain, and there can be little doubt that the fibre is actually to some extent digested, for the stomach shows some modifications of structure such as we commonly find in other animals that are accustomed to swallow large quantities of innutritious food-material. The pulpy residue after digestion passes from the intestine into the gill-passages, and is expelled with the outgoing water through the shorter siphon.

SEA ORGANISMS DESTRUCTIVE TO TIMBER.

1.

Fig. 1. *Teredo* sp. The entire animal as extracted from its burrow, somewhat contracted in preservation. The anterior or inner end, with the valves of the shell, is on the right, and the fleshy foot is seen in the notch of the shell-valve. At the left extremity are the two siphons, the ventral or inhalent one fringed at the tip and longer than the dorsal or exhalent siphon. At the base of the siphons are the two pallets. Actual length of specimen 7 inches.



2.

3.

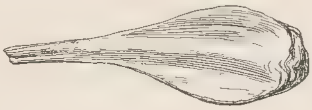
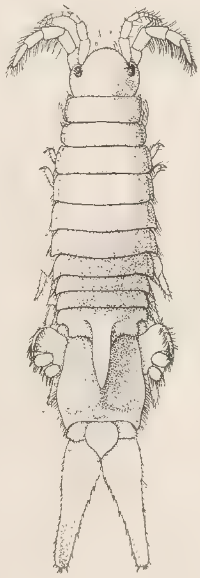


Fig. 3. *Teredo norvegica.* One of the pallets, inner surface. Actual length $\frac{7}{8}$ inch.

Fig. 2. *Teredo norvegica.* The right valve of the shell, outer surface. The anterior margin (to the right) shows the right-angled notch which, in the living animal, is occupied by the foot. Parallel to the sides of this notch the surface of the shell shows the fine ridges, or rather rows of minute teeth, which are the instruments of boring. Actual size $\frac{3}{8} \times \frac{3}{8}$ inch.

6.



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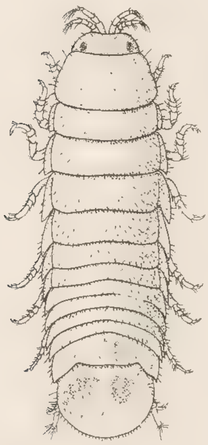

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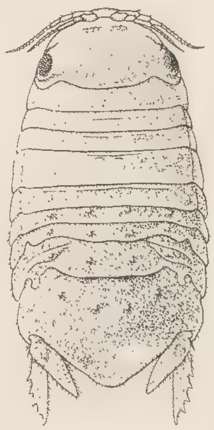

Fig. 4. *Limnoria lignorum.* From the dorsal surface. Actual length $\frac{1}{6}$ inch.

Fig. 5. *Sphæroma terebrans.* From the dorsal surface. Actual length $\frac{1}{2}$ inch.

Fig. 6. *Chelura terebrans.* Male, from the dorsal surface. Actual length about $\frac{1}{4}$ inch. The female is similar but with shorter tail-appendages and dorsal spine.

7.

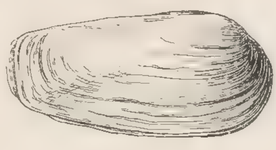

Fig. 7. *Saxicava rugosa.* Shell, from the side. One of the commonest species of rock-boring Mollusca on the British coasts. Actual length about 1 inch.

Drawn from specimens in the British Museum (Natural History).

As a rule the ship-worm enters the surface of a piece of timber at right angles to the grain of the wood, but the burrow soon curves round to run with the grain, generally upwards, avoiding knots and other obstacles, and never breaking into neighbouring burrows even when only a thin partition separates them. The inside of the burrow is lined with a layer of shelly material which may be only a thin film or may increase in thickness, particularly near the opening when the superficial decay of the wood has left it projecting as a shelly tube. In some species the lining of the burrow may show successive rings projecting inwards so as to divide the tube partially into a series of chambers.

Some species of *Teredo* are stated to have both sexes united in each individual, but in other species the sexes are separate. The eggs and sperm are usually shed free into the water, and fertilisation takes place after the eggs are expelled. In *Teredo navalis*, however, the eggs are fertilised within the body of the female by sperm drawn in with the entering current of water, and the early stages of development are passed through within the gill-chamber. In either case the egg develops in a few hours into a minute larva, which swims freely through the water by means of a circlet of cilia. Very soon the beginnings of the shell are visible and the larva becomes like a microscopic swimming cockle, the bivalve shell enclosing the whole body, not, as in the adult, only an inconsiderable part of it.

There is something of a gap at this point in our knowledge of the life-history. The next stage known is that in which the larva ceases to swim and settles down on a suitable piece of wood. How long an interval of time there is between these stages is not precisely known. The Dutch Commissioners estimated that the larvæ settling on the wood were about four days old, but Sigerfoos considers that in the species studied by him the larvæ must be at least a month old. Probably the period may vary according to the species observed and the temperature and other conditions prevailing. The point is of some practical significance, for it is during this free-swimming period alone that the ship-worm possesses the power of locomotion, and is able to infect timber hitherto untouched. On the length of this period depends the distance to which the larvæ may be carried by marine currents before they adopt the sedentary life of the adult.

When it settles on the surface of the wood the larva soon loses its cilia, but is able to crawl about by means of a large muscular organ known as the foot. When it finds a suitable place for boring it attaches itself by means of a sticky thread, the "byssus," and begins to scrape away the fibres of the wood with the edges of its valves. While thus engaged it was found by Sigerfoos to cover itself with particles of wood and other substances stuck together to form a protective case. Under this covering it works rapidly and soon disappears beneath the surface. In the species studied by Sigerfoos, the larva, on settling, measures less than 1/100th of an inch in length, and although the opening of the burrow is somewhat enlarged later, it may be little more than a pinhole, even when the ship-worm is full grown. These minute openings may be the only external evidence that a piece of timber has been attacked.

The rate of growth of the ship-worm after it has entered the wood depends probably on a combination of factors. According to Sigerfoos, the abundance of the food supply from the floating organisms of the water is more important, in this respect, than the hardness of the wood in which the animal is burrowing, and he found it to grow quite as rapidly in hard yellow pine as in soft white pine. He gives the following figures for the rate of growth of *Xylotrya gouldii*:—

	Length in Millimetres.	
Newly attached	0·25	(·01 inch)
12 days after attachment . . .	3·0	(·12 „)
16 „ „ „ . . .	6·0	(·25 „)
20 „ „ „ . . .	11·0	(·5 „)
30 „ „ „ . . .	63·0	(2·5 „)
36 „ „ „ . . .	100·0	(4·0 „)

Specimens of *Teredo dilatata* 4 feet long were estimated by the same author to be "little, if any, over a year old," but Orton (1914) at Plymouth, found that *Teredo navalis* took thirty-one weeks to reach 198 mm. (7·8 inches), its burrows being 280 mm. (11 inches) long by about 10 mm. (0·4 inch) in diameter.

The breeding season of *T. navalis* in Holland appears to be in the summer months, eggs being found in the females in June and July, while larvæ were found on the surface of the wood from the end of July until September. At Beaufort, North Carolina, Sigerfoos found both *Xylotrya* and *Teredo* containing ripe sexual products from early in May until at least the middle of August. According to Quatrefages, on the north coast of Spain only a few specimens survive over the winter. Even on the Dutch coast, however, some of them certainly do survive.

Ship-worms extracted from their burrows have been kept alive in sea-water for more than a fortnight. On the other hand, Orton (1914) found *T. navalis* to be alive a fortnight after the wood containing it had been taken from the water, and he adds, "Thus these animals would be able to live easily during the period for which most vessels would be in dry dock for scraping and painting."

The ship-worms seem to require clear and fairly pure water for their development. It has been observed that piles placed in muddy water or in water heavily contaminated with sewage are less attacked. With regard to the salinity of the water the various species differ much in their requirements. *Teredo navalis* appears to be intolerant of brackish water. The great epidemics of ship-worm in Holland due to this species in 1730–32, 1770, 1827, and 1858–59 are stated to have been associated with reduced rainfall, leading to unusually high salinity in the waters of the Zuyder Zee. Certain tropical species, however, live in fresh water. Thus *Nausitora dunlopei* from the river Comer, a branch of the Ganges, *N. fluviatilis* from Fiji, and an unnamed species from the Zambesi at a distance of 250 miles from the sea, are all stated to have been found in perfectly fresh water.

The most favourable temperature probably also differs in the various species, although here we have even less satisfactory data to go upon.

Sigerfoos found *Xylotrya gouldii* very abundant at Beaufort, North Carolina, while *Teredo navalis* occurred sparingly and was of small size, and he attributes the poor development of the latter species to the high salinity of the water and the longer warm season.

The greatest depth at which the ship-worms may attack timber does not appear to have been satisfactorily determined, but a species of the related genus *Xylophaga* is stated by Dr. Dall to have been found in a telegraph cable in the North Atlantic at the great depth of 1500 fathoms.

Little is known as to the natural enemies of the ship-worms. In Holland they have been stated to be attacked by a predaceous annelid worm identified as *Nereilepas* (or *Lycoris*) *fucata*, which enters their burrows and devours them piecemeal. We have no knowledge, however, as to how far the attacks of the annelid are efficient in checking the depredations of the ship-worm, and suggestions that have been made for introducing it into Australian waters are, to say the least of it, premature.[1]

A discussion of the various measures adopted for preventing the attacks of shipworms does not fall within the scope of this report, but reference may be made to the important investigations recently carried out in America on the poisonous effects of creosote and its various constituents. Dr. Shackell (1914, 1916) experimented with living specimens of *Xylotrya* extracted from their burrows and placed in sea-water. Definite quantities of the various substances were added and the time was noted at which degenerative changes began to appear. Briefly, it was found that the products of the fractional distillation of creosote are more poisonous the lower the boiling point. This is mainly due to the creosote oils, of which the lighter, such as benzol, are more poisonous than the heavier, such as xylol. The tar-acids (phenol, &c.) and bases (quinoline, &c.) are highly poisonous, but in these the toxicity increases the higher the boiling point. The solid hydrocarbons (naphthalene, &c.) were found to be only very slightly poisonous. These results, obtained in the laboratory, were not quite in accordance with the results of practical tests, for it was found that "the highest boiling fraction, which was the least poisonous, stood up the best in actual service" (Teesdale and Shackell, 1917). It is suggested, in explanation of this, that the more volatile constituents, when used alone, are rapidly dissipated by solution in the sea-water, while "the high-boiling, relatively non-volatile constituents tend to prevent the loss of lower-boiling, poisonons substances." It is pointed out, however, that other, more obscure factors may also come into play.

The classification of the ship-worms is not in a satisfactory condition, from the point of view of the zoologist, and a systematic revision of the group is greatly needed. As already stated, nearly all the species which are of practical importance are members of the family Teredinidae, but a number of the species that have been described and some of the genera among which they are distributed are of doubtful validity. The typical

[1] It should be stated that Prof. W. C. M'Intosh (1908), whose authority in matters relating to Annelida is unquestioned, does not believe that *Nereilepas* attacks the ship-worm in its burrow. [But see p. 218, Rept. of Mr. P. G. Messent on Bombay. (Eds.)]

genus *Teredo*, of which the general structure has been described above, is distinguished chiefly by the form of the pallets, which are simple paddle-shaped structures. About a score of species have been referred to the genus. *T. navalis* is the species doing damage in Holland and on many parts of the British coasts. It is also found on the Atlantic coast of North America, and, according to recent accounts (Gatliffe and Gabriel, 1915), on the coast of Victoria, Australia. *T. norvegica* (also called *T. bruguieri*) is a somewhat larger species, with differently shaped pallets. It is common on the British coasts, while in Norway its range extends within the Arctic Circle, specimens being reported from West Finmark at about 70° N. Lat. It is well known that ship-worm is extremely active in Australia and New Zealand, and a species that does great damage in these waters has been stated to be identical with *T. norvegica*, but its exact identification is not yet certain. Another large species. *T. megotara*, is not unfrequently found in British waters but chiefly, it appears, in floating timber. *T. dilatata* is common on the Atlantic coast of North America.

The genus *Xylotrya*, as already stated, is distinguished from *Teredo* chiefly by the segmented pallets. The species are especially developed in the warmer seas, although several have been found on the British coasts. *X. gouldii* is very abundant at Beaufort, North Carolina.

Several other genera have been distinguished under the names *Nausitora*, *Calobates*, etc., but their validity is open to doubt, and some zoologists even go so far as to group all the known ship-worms under the single genus *Teredo*.

Closely allied to the Teredinidæ is the family Pholadidæ, including the rock-boring *Pholas* and its allies (some species of which have occasionally occurred in timber), and a few timber-boring species in the genera *Martesia* and *Xylophaga*. All these are distinguished from the Teredinidæ by the absence of pallets and by the fact that their burrows are not lined with shell. *Xylophaga dorsalis* has been reported as doing serious damage to dock gates at Ardrossan on the Firth of Clyde (Thompson 1847). Its burrow does not exceed $1\frac{1}{2}$ inches in depth.

B.—The Gribble (*Limnoria*).

It is of interest to recall the fact that the Gribble was first discovered as a British animal by Robert Stevenson, who found it damaging the timber work employed in the building of the Bell Rock Lighthouse. Specimens were sent by him about 1814 to Dr. Leach of the British Museum (where they are still preserved), by whom they were described under the name *Limnoria terebrans*. Still earlier, however, the species had been found by a Norwegian zoologist, H. Rathke, who gave it the name of *Cymothoa lignorum*. According to the rules of zoological nomenclature, therefore, the proper name of the species is *Limnoria lignorum* Robert Stevenson carried out at the Bell Rock a lengthy series of experiments, extending over thirty years, on the resistance of various kinds of timber to the attacks of *Limnoria*. The results of these experiments are recorded in an article by his son, Thomas Stevenson

(1856). Another son, David Stevenson, also wrote (1862 and 1875) on the protection afforded by cresoting timber, and on the resistance of Greenheart to the attacks of the gribble. Coldstream (1834) gave a detailed account of the structure and habits of the animal. Among many subsequent writers, the late Dr. P. P. C. Hoek (1893), in a very elaborate report to the Amsterdam Academy of Science, dealt at length with the anatomy, habits, and destructive activities of *Limnoria*, and with the means of preventing its attacks.

Limnoria is not unlike a miniature woodlouse in appearance, see Fig. 4, p 64, and it belongs, like the woodlice, to the Order of Crustacea known as Isopoda. It measures from $\frac{1}{8}$th to $\frac{1}{6}$th of an inch in length, and has a small head and a segmented body ending in a broad tail plate. The head bears a pair of eyes, two pairs of short feelers or antennæ, and, on the under side, four pairs of jaws, including the strong mandibles with horny tips which are the organs by which boring is effected. There are seven pairs of short legs ending in sharp hooked claws, which enable the animal to cling to the surface of the wood and to move up and down in its burrow. Under the tail are five pairs of appendages each composed of two flat membranous plates which serve as gills. These gills are, in the living animal, in constant movement, causing a current which serves to renew the water needed for respiration. When out of its burrow the animal uses these plates as paddles in swimming. It possesses the power of contracting its body into the form of a ball, although not so perfectly, perhaps, as is the the case with *Sphæroma*.

The burrows formed by *Limnoria* are usually not more than $\frac{1}{20}$th inch wide and of the same diameter throughout. They are stated to reach $1\frac{1}{2}$ to 2 inches in length, but owing to their oblique direction the actual depth of penetration is not, as a rule, more than about $\frac{1}{2}$ an inch. The fact that the burrows are of uniform diameter indicates that the animal begins new ones as it increases in size, and as they break into each other in all directions the superficial layer of the wood rapidly becomes reduced to a spongy mass. As a rule, *Limnoria* keeps to the softer parts of the wood, and in a piece of timber with well-marked annual rings, the soft spring wood is rapidly bored away, leaving the harder layers of autumn wood projecting and giving a very characteristic appearance to the surface. As the honeycombed surface wood is easily removed by the action of the waves the deeper layers are laid open to attack, and in course of time the timber may be entirely destroyed.

It is very likely that a limit is set to the depth of the burrows by the difficulty of respiration. As already stated, the necessary current of water is kept up by the fanning movement of the gill-plates themselves, and it may easily be supposed that this movement is insufficient to maintain a regular circulation at the inner end of the narrow tubular burrow beyond a certain depth.

Limnoria undoubtedly swallows the wood which it gnaws away in forming its burrow. Whether it has any other source of nourishment is not known.

As in most Crustacea the sexes are separate and fertilisation is internal. The eggs are carried until they hatch in a brood-pouch on the

under side of the female. The number in a single brood is generally not more than ten, but may be as many as seventeen. The young, when hatched, differ little, except in size, from the adults. Contrary to what is the case with most marine animals, the young appear to be of a less wandering disposition than their parents, for it is stated by Hoek that the first to attack a piece of timber are always the older individuals.

Like some of the species of ship-worms, *Limnoria* is unable to bear too great a reduction of salinity, but here, as in so many other cases, there is a lack of precise data. Hoek found that, on the Dutch coast, an admixture of fresh water did not appear to disturb the animals unless the average salinity fell below 2 per cent. It was stated in 1835 by W. Thompson that *Limnoria*, although abundant at Leith, was not found at Dundee, probably owing to the lower salinity of the water there. Whatever may have been the case at that time, the animal is now, and has been for a good many years, abundant in Dundee Harbour.

The attacks of *Limnoria* are stated to be most severe between low water and half-tide mark, although it may occur near high-water mark, where it is only submerged for a short period at each tide. A point of some practical importance is that the animals have been found alive from ten days to a fortnight after the timber in which they were boring had been taken out of the water. It has been stated that they do not attack floating timber. Shackell (1916) found that the relative toxicity of the fractions of creosote for *Limnoria* was the same as for *Xylotrya*.

Six species of the genus *Limnoria* have been described, but two of these are not known to bore into wood. The common *L. lignorum* is found on the coasts of Europe from the Lofoten Islands to the Black Sea, and on the Atlantic and Pacific coasts of North America. In the southern hemisphere it has been recorded from the Falkland Islands, Port Elizabeth, Sydney, Wellington and Auckland. On the other hand, a distinct species, *L. andrewsi*, was found by Dr. C. W. Andrews boring in the piles of a jetty at Christmas Island, Indian Ocean (Calman 1910).

C. Sphæroma.

The genus *Sphæroma* is closely allied to *Limnoria*, and includes a large number of species from all regions of the globe, but only a few of them have the habit of boring in timber, see Fig. 5, p. 64. One such species was described from Brazil, another from Florida, and a third from India. Stebbing (1904) regards all these as belonging to a single species, which he records also from the Cape and from Ceylon. Hedley (1901) records two other species as destroying timber in Australia and New Zealand. The question as to the identity or distinctness of the various forms can only be decided when we are able to compare, side by side, specimens from all these widely-separated localities. At all events they are very closely related, differing from *Limnoria* in a number of small characters that need not be enumerated here, but of larger size, measuring $\frac{3}{8}$ of an inch or more in length and making burrows about $\frac{1}{5}$ of an inch in diameter. The habit of rolling up into a ball is more marked than it is in *Limnoria*, and preserved specimens are generally found in this attitude.

Little is recorded as to their habits. The species found in Florida

occurs in fresh water, and from some other localities they are recorded as found in estuaries or lagoons where the water is probably brackish.

The most serious damage by *Sphæroma* is reported from Florida (Teesdale and Shackell, 1917). According to Mr. Walsh's report from Sydney in the present volume *Sphæroma* is much less destructive than *Limnoria*. The observation that they "in a measure afford protection against the more rapid and certain destruction of the *Teredo* and *Limnoria*" is noteworthy and deserves further investigation.

D.—Chelura.

Very often on the British coasts *Limnoria* is accompanied by another wood-boring Crustacean, *Chelura terebrans*. This is a member of the Order Amphipoda, an order which includes, among many other forms, the common "Sand-hoppers." It is slightly larger than *Limnoria*, measuring $\frac{1}{8}$th to $\frac{1}{4}$th of an inch in length, and may be distinguished from it by the much larger and stronger antennae, by the pair of large tail-appendages (uropods) at the hinder end of the body, and by the sharp spine projecting from the middle of its back, see Fig. 6, p. 64.

The burrows made by the full-grown *Chelura* are usually wider than those of *Limnoria*, reaching $\frac{1}{10}$th of an inch in diameter. It is stated that they are driven more obliquely or even parallel to the surface of the wood, but examination of actual specimens shows that this is not invariably the case.

Whether *Chelura* ever occurs independently of *Limnoria* is not quite clear, although it is certain that *Limnoria* is often found alone. Allman (1847) states that "upon the whole, *Chelura* would seem to be a still more destructive creature than *Limnoria*," but subsequent writers do not seem to have attached so much importance to it, although it is probable that damage attributed to the better known *Limnoria* has often been due to the two species working together.

Until recently only a single species of the genus was known. Described in 1839 from Trieste, *Chelura terebrans* has since been found at many points on the coasts of Europe from Norway to the Black Sea and also on the Atlantic coast of North America. It has recently been identified by Chilton (1914) from Auckland, where it was associated with the European species of *Limnoria*. Curiously enough a second species (*Chelura insulæ*) was discovered at Christmas Island, Indian Ocean, in company with a distinct species of *Limnoria* (Calman, 1910).

E.—General Remarks on Timber Pests.

It seems to be generally agreed that the most serious enemies of submerged timber are the Teredinidae on the one hand and *Limnoria* on the other, and it may be of interest to point out some contrasts in their respective modes of attack. The ship-worms, making a minute opening in the surface of the wood, may penetrate far into the interior, and where their burrows are numerous they may seriously weaken a pile that shows comparatively little external signs of damage. Since the animal never leaves its burrow, the number of individuals that can penetrate from a

small unprotected space (as, for instance, from a fault in the sheathing) is limited to the number of larvæ that can find foothold in the space, but as the larvæ are very small, that number may be relatively considerable. Further, owing perhaps to the very elaborate respiratory system, with passages connected with the siphons for the entrance and emission of water, the length of the burrows may be very great, in some cases up to 4 or 6 feet, and timber may be damaged up to that distance from the point of entrance. *Limnoria*, in contrast to this, works always near the surface. The difficulty of obtaining the necessary currents of water for respiration prevents it from driving its burrows beyond an average depth of ½ inch or so. In compensation for this, however, it retains throughout life the power of moving freely and beginning new burrows, and it rapidly destroys the superficial layers of the wood. The damage so caused is visible externally almost to its full extent. An unprotected space results only in local damage which need not become serious. Dr. Hoek points out that "scupper-nailing" is even more effective as a protection against *Limnoria* than against *Teredo*. "If a nail-head be broken off or a spot left uncovered by negligence, the *Teredo* may enter and destroy the wood; *Limnoria* could only do damage at the surface, and its spreading, as well as the breaking away of the attacked wood, which is a necessary condition for its deeper penetration, would be prevented by the surrounding nails," Hoek further points out that, while thorough treatment with creosote affords some protection from *Limnoria* no less than from *Teredo*, the gradual washing out of the creosote from the superficial layers renders them accessible to the former pest long before there is any need to fear the attacks of the latter.

A further contrast between the shipworm and *Limnoria* is found in the mode of infection of new timber. The former is free-swimming only in its earliest stages, while in the latter it is full-grown specimens that are found to attack new timber. This may be of importance in relation to the experiments of Teesdale and Shackell (1917) on the effect of sheathing creosoted piles with untreated boards. They found that the larvæ of *Xylotrya*, obtaining entrance into the untreated wood, were able to penetrate from it into the creosoted wood, while unsheathed control piles alongside were untouched.[1] They point out that spots where the creosote penetration is imperfect, such as knots or resin streaks, may afford an entrance for the ship-worms like that given by the untreated boards in their experiments. They attribute this result to the greater susceptibility of the larval shipworms to the poisonous effects of the creosote. If this be so, it seems likely that a different result would be obtained with *Limnoria*, which attacks in the adult state. It is not easy, however, to see why the poisonous constituents of creosote should not take effect on the full-grown ship-worms since the bored wood is swallowed and probably partially digested by them.

In earlier times statements were commonly made that the ship-worm had been introduced into British or Dutch waters by shipping from other

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[1] It appears to have escaped notice that the same observation was made in the case of *Teredo* by the Amsterdam Commission (1860, pp. 10 and 117).

countries, and especially from the East or West Indies. It is certain that this is not the case, and the origin of the belief was no doubt the occasional excessive multiplication of the pest in places where it had formerly been overlooked. It is not at all unlikely, however, that accidental introduction by wooden ships may have been responsible for the appearance of European species of timber pests in such places as Australia and New Zealand, although in the case of *Limnoria* this assumption would be in conflict with the statement that the species does not attack floating timber.

III. ANIMALS BORING IN STONE.

The marine organisms boring in stone are more numerous and more diverse than those that destroy timber. Apart from the minute boring algæ that disintegrate shells and corals, but are hardly likely to concern the engineer, many animals bore into limestone, and some into sandstone, shale and even harder rocks. A number of sponges, of which the best known belong to the genus *Cliona*, bore into limestone and other calcareous rocks as well as into shells. Certain Polychæte and other worms, mostly of small size, but occasionally present in vast numbers, occur in the same habitats and some of them have also been found in sandstone and shale. It has been stated that *Limnoria* has been found boring in limestone, but the observation has not been confirmed, and appears to have been an error. It has also been asserted that some species of *Sphæroma* burrow in sandstone, but it is not quite certain that the animals really excavate the holes in which they are found. The most conspicuous rock-boring animals, however, are lamellibranchiate (or bivalve) Mollusca. The various species of *Pholas* and allied genera, which are closely related to the Teredinidae, are the best known. *Pholas dactylus*, the "Piddock," is the largest of the British species, its shell measuring five to six inches in length, by one and a half inches broad, and its burrows may be a foot deep. *Lithophaga* (or *Lithodomus*), the "Date-shell" of the Mediterranean, is closely allied to the common Mussel. *Saxicava*, belonging to yet another family, is common on the British coasts, see Fig. 7, p. 64. Its burrows, which may be six inches deep, are usually, but perhaps not always, in calcareous rocks.

In all these cases the method of boring has been the subject of much discussion. It is certain that it is not the same in all, and in some it still remains a matter for conjecture. In *Pholas* and its allies, which bore not only into limestone but also into sandstone, shale, peat, and even, occasionally, into wood, there can be little doubt that the shell is employed as a rasping organ, much as it is in *Teredo*. In *Lithophaga*, which is only found in limestone, it seems certain that the rock is dissolved away by chemical means, and an acid-secreting gland, which is not found in non-boring forms, is regarded, with considerable probability, as the source of the solvent. In *Saxicava*, which is said not to be confined to calcareous rocks and has a shell not obviously fitted for boring, the process has not been satisfactorily explained. The case of the worms is still more obscure. The sponges are quite incapable of boring by mechanical means, but the nature of the solvent action which they exert upon calcareous substances has not been fully elucidated.

The best known case in which rock-boring animals have caused considerable surface injury to an engineering work is that of Plymouth breakwater. The damage here has been going on for many years. Some time ago Dr. E. J. Allen, Director of the Plymouth Marine Laboratory, was asked by the Government engineers in charge of the Breakwater to investigate the subject. He states (1904), "In a stone which has been injured through this cause, the outer surface, to the depth of about a quarter of an inch, is converted into a honeycombed, friable mass through the ravages of the boring sponge *Cliona celata*, whilst at frequent intervals larger holes, each of which may have a diameter of a quarter of an inch, and may pierce the stone to the depth of an inch, are formed by the boring mollusc *Saxicava rugosa*. To these two animals most of the damage is due, but in addition there are found a few holes bored by the mollusc *Gastrochæna dubia*, and many by the Polychætes *Dodecaceria concharum*, *Polydora ciliata*, *Polydora hoplura*, and *Potamilla reniformis* . . . . *Dodecaceria* forms holes of oval or figure of eight section, which may penetrate for a depth of several inches into the heart of the stone; *Polydora ciliata* forms small U-shaped burrows, open at each end, whilst *P. hoplura* makes similar burrows of larger size."

IV. SUGGESTIONS FOR RESEARCH.

It is clear from the sketch that has been given above that there are many important gaps in our knowledge of the natural history of the various animals concerned. While the filling up of these gaps is the business of the zoologist, and is desirable, in the first place, in the interests of zoological science, it is not unreasonable to ask the engineer to take an interest in research directed to this end. It is obviously impossible to prophesy that the results will have any immediate practical application. Even if we knew, in every detail, the structure, life-history and habits of every one of the species, it might still prove impossible to devise any effective means of meeting or avoiding their attacks; but it is quite certain that every advance of knowledge on these subjects brings with it an additional chance of finding such means.

The following suggestions indicate only a few of the lines along which investigations might be directed.

It has already been pointed out that a systematic revision of the species of animals concerned is a necessary preliminary for further research. It is hoped that the measures now being taken by the committee will result in obtaining a collection of specimens from various parts of the world, and that a study of this material may enable a more precise determination of the species to be made. Along with this it should be possible to collect data as to the relations of the different species to salinity, temperature, food-supply and the like, and as to breeding seasons, hibernation, and rate of growth.

More special investigations might be instituted with a view to the determination of the relative abundance or scarcity of some of the species on different parts of the same coast-line, and also the fluctuations in abundance in the same place over a series of years. It might be possible

to correlate these facts with hydrographical or meteorological conditions such as oceanic currents or rainfall, as has been done, to some extent, on the Dutch coast. The relative abundance of the minute floating life of the sea, known as the plankton, might also be found to have some bearing on the subject, since it furnishes at least a part of the food in the case of the ship-worms. Attention should also be given to the duration of the larval period and the distance to which larvæ might be carried by currents, as well as to the possibility of "infection" being carried by drift wood or by wooden ships. On all these points we have little information even as regards the British coasts, and none at all us regards most other parts of the world. Such a survey, if it did nothing more, might at all events afford hints to the engineer as to where and at what seasons he should be on the watch for evidence of damage to timber structures.

It is also possible that something of value might result from an investigation into the natural enemies, parasites and the like, of the timber pests.

Finally, and most important of all from the practical point of view, much remains to be done in elucidating the precise mode of action of the various protective means employed or suggested for employment. The American investigations on the toxicity of creosote mentioned above should be extended to other substances, and the experiments on "baiting" with untreated wood deserve to be repeated under varying conditions. It might prove worth while, if possible, to investigate the processes of digestion in *Teredo* and *Limnoria* with a view to finding whether they could absorb poisonous substances insoluble in sea-water.

V. LIST OF BOOKS AND PAPERS REFERRED TO.

ALLEN, E. J. 1904. Journal of the Marine Biological Association. VII. p. 163.

ALLMAN, G. J. 1847. "On *Chelura terebrans*, Philippi; an Amphipodous Crustacean destructive to Submarine Timber Works." Annals and Magazine of Natural History. XIX. pp. 361–370, pls. xiii & xiv.

AMSTERDAM COMMISSION. 1860–1869. "Verslag over den Paalworm, uitgegeven door de Natuurkundige Afdeeling der Koninklijke Akademie van Wetenschappen." pp. 158, 4 pls., 4 tables. Amsterdam, 1860.

The succeeding Reports were published in Mededeelingen der Koninklijke Akademie van Wetenschappen, XII. (1861), p. 133; XIII. (1862), p. 318; XV. (1863), p. 293; XVII. (1865), p. 74; (Reeks II.), I. (1866), p. 157; III. (1869), p. 207.

BAUMHAUER, E. H. VON. 1866. "Sur le Taret et les moyens de préserver le bois de ses dégâts." Archives Néerlandaises des Sciences exactes et naturelles. I. pp. 1–45, pls. i–iv.

BAUMHAUER, E. H. VON. 1869. "Sur les moyens de préserver le bois des attaques du Taret." Op. cit. IV. pp. 160–166.

BORLEY, J. O. 1909. "Notes on British Marine Boring Organisms." Report Royal Commission on Coast Erosion. Vol. II. Pt. 2. Appendix XXIX. pp. 1–3.

CALMAN, W. T. 1910. "On two New Species of Wood-Boring Crustacea

from Christmas Island." Annals and Magazine of Natural History. Ser. 8. V. pp. 181–186, pl. v.

CHILTON, C. 1914. "The species of *Limnoria:* a genus of wood-boring Isopoda." Annals and Magazine of Natural History. Ser. 8. XIII. pp. 380–389 & 448, pl. xvii.

COLDSTREAM, JOHN. 1834. "On the Structure and Habits of the *Limnoria terebrans:* a minute crustaceous animal, destructive to marine wooden erections, as piers, &c." Edinburgh New Philosophical Journal. XVI. pp. 316–334, pl. vi.

GATLIFFE, J. H., and GABRIEL, C. J. 1915. "Notes on some Victorian species of *Teredo.*" Proceedings of the Royal Society of Victoria. XXVIII (n.s.). pp. 115–123, pls. xii & xiii.

HATSCHEK, B. 1880. "Ueber Entwicklungsgeschichte von *Teredo.*" Arbeiten aus dem zoologischen Institut der Universität Wien. III. pp. 1–44, pls. i–iii.

HEDLEY, CHARLES. 1901. "The Marine Wood-Borers of Australasia and their Work." Report of Eighth Meeting, Australasian Association for the Advancement of Science, Melbourne. pp. 237–255, pls. vii–x.

HOEK, P. P. C. 1893. "Rapport der Commissie . . . betreffende de levenswijze en de werking van *Limnoria lignorum.*" Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam (Tweede Sectie), Deel I. No. 6. pp. 103, xcvi, 7 pls.

M'INTOSH, W. C. 1908. "On the Perforations of Marine Animals." The Zoologist. (Ser. IV.). XII. pp. 41–60.

ORTON, J. H. 1914. Journal of the Marine Biological Association. X. p. 320.

QUATREFAGES, A. DE. 1849. "Mémoire sur le genre Taret (*Teredo*, Lin.)," Annales des Sciences Naturelles. Zoologie (Ser. iii.), XI., pp. 19–73, pls. i. and ii.; "Mémoire sur l'embryogénie des Tarets." T.c., pp. 202–228, pl. ix.

SELLIUS, Godofredus. 1733. "Historia naturalis Teredinis, seu Xylophagi marini..." 4to. Trajecti ad Rhenum.

SHACKELL, L. F. 1914. "The comparative toxicity of Coal-tar Creosote and Creosote distillates and of individual constituents for the marine wood-borer, *Xylotrya.*" Eleventh Annual Proceedings of the American Wood Preservers Association. Engineering Record, Sept. 12, 1914, 16 pp. with figures (Reprint).

SHACKELL, L. F. 1916. "Marine Borers from Wood Preserver's Standpoint." Railway Age Gazette, March 17, 1916, 3 pp. (Reprint).

SIGERFOOS, Charles P. 1908. "Natural History, Organization, and late Development of the Teredinidæ or Ship-worms." Bulletin of the Bureau of Fisheries. Washington. XXVII., pp. 191–231, pls. vii.–xxi.

STEBBING, T. R. R. 1904. "Gregarious Crustacea from Ceylon." Spolia Zeylanica. II., pp. 1–29, 7 pls.

STEVENSON, David. 1862. "Notice of the ravages of the *Limnoria terebrans* on creosoted timber." Proceedings of the Royal Society of Edinburgh. IV., pp. 612–616.

STEVENSON, David. 1875. "Notice of the ravages of the *Limnoria terebrans* in greenheart timber." Op. cit. VIII., pp. 182–185.

STEVENSON, Thomas. 1856. Article, "Harbours." Encyclopædia Britannica, 8th Edition.

TEESDALE, C. H., and SHACKELL, L. F. 1917. "Field Tests made on Oil Treatment of wood against marine borers." Engineering News Record. November 1st, 1917, pp. 833–837, with figures.

THOMPSON, William. 1847. "Note on the *Teredo norvegica* (T. *navalis*, Turton, not Linn.), *Xylophaga dorsalis*, *Limnoria terebrans*, and *Chelura terebrans*, combined in destroying the submerged wood-work at the harbour of Ardrossan, on the coast of Ayrshire." Annals and Magazine of Natural History. XX., pp. 157–164.

POSTSCRIPT.

Two important papers which have come to my notice since the foregoing report was in type deserve to be noted.

BARROWS, A. L. 1917. "An unusual extension of the distribution of the Shipworm in San Francisco Bay, California." University of California publications, Zoology. XVIII, No. 2, pp. 27–43.

This paper deals with outbreaks of Shipworm in 1914 and 1917 at the Navy Yard, Mare Island, San Francisco Bay, where no damage from this cause had been previously reported. It is shown that these outbreaks followed years in which the outflow of the rivers running into San Francisco Bay was abnormally low.

CHILTON, C. 1919. "Destructive Boring Crustacea in New Zealand." New Zealand Journ. Science and Technology. II, pp. 3–15, 12 text figs.

Prof. Chilton states that *Sphæroma quoyana*, whose rock-boring habits have been doubted, really does bore into sandstone and claystone. He states that it has caused serious damage to harbour works at Wairoa, Hawke's Bay, New Zealand, by undermining and destroying walls built on, or constructed of, a kind of claystone known locally as "papa rock."

NOTES ON SPECIMENS OF WOOD-BORING ANIMALS SUBMITTED TO THE COMMITTEE.

By W. T. CALMAN, D.Sc.

In response to a request circulated by the Committee, important collections of marine timber pests have been received from Corresponding Members in charge of the ports hereafter mentioned. A detailed investigation of this material is in progress at the Natural History Museum, but will take some considerable time to complete, and it is thought desirable to publish the following preliminary note.

Collections have been received from the ports of Leith, Southampton, Simon's Town, Brisbane, and Auckland.

Ship-worms (*Teredinidae*) are reported as doing serious damage at

Simon's Town, Brisbane, and Auckland. From Simon's Town two species were sent, one apparently identical with the European *Teredo navalis*, the other a species of *Xylotrya* not yet identified, but different from any other in the collection. At Brisbane two species also occur, one being a large *Teredo* provisionally identified *T. manni* described from Singapore. The other species is the well-known *Xylotrya saulii*, and this occurs also at Auckland. It is especially worthy of note that the Simon's Town species are different from those doing damage at Brisbane and Auckland, and it is therefore not to be assumed without trial that preventive measures efficacious in the one locality would be equally so in the others.

Among the Crustacea, *Limnoria lignorum* (the Gribble) occurs alone at Leith. At Southampton, as is usual on the South coast of England, it is accompanied by *Chelura terebrans*. Both species occur together at Simon's Town, where the great preponderance of *Chelura* is a very unusual feature. *Limnoria* is also very destructive at Auckland. The occurrence of *Chelura* at that port has been ascertained by Prof. Chilton, but specimens sent to us under that name prove to be *Corophium contractum*, a species not known to bore into wood. As *Corophium* has a superficial resemblance to *Chelura*, it seems likely that the collector has been misled by this. *Sphæroma terebrans* is evidently abundant and destructive at Brisbane, from which port numerous specimens were sent. From Simon's Town we have received, under the name of *Sphæroma*, an allied but quite distinct Crustacean, *Parisocladus stimpsoni*. This also may be merely an error of identification on the part of the collector, since *Parisocladus* is not known to bore into wood, but the possibility that it may do so must not be lost sight of. If *Sphæroma* had been present in sufficient numbers to cause serious damage it is hardly likely that it could have been entirely overlooked.

The collections already received promise results of much scientific interest and of possible practical importance. It is greatly to be desired that they should be supplemented by collections from other ports where damage by wood-boring animals is reported.

THE CORROSION OF IRON AND STEEL

By J. NEWTON FRIEND, D.Sc.

DIFFERENT TYPES OF CORROSION.

By the term "Corrosion" is understood the destruction or disintegration of a metal, usually as a result of oxidation. The term is used rather widely, however, and comprises several distinct phenomena, the more important of which, in the case of iron and steel, are as follow :—

1. *Rusting.*—When a piece of iron[1] is exposed to a damp atmosphere its surface unites with oxygen and moisture, forming a brown, porous and friable coating of hydrated ferric oxide. This is commonly known as rust, and the rusting of iron is one of the most important types of corrosion of that metal.

2. *Graphitization* is a type of corrosion to which cast iron is specially liable,[2] but it has also been observed in the purer forms of the metal,[3] such as wrought iron, particularly after long immersion in sea-water. It is caused by the more or less complete conversion of the metal into ferrous oxide which retains the original shape of the metal and which, in the case of cast iron, is admixed with the unaltered graphite. The oxidised mass is soft, and can be easily cut with a knife.

3. *Solution in Acid.*—Iron is readily attacked by the majority of acids, even when the latter are dilute, yielding ferrous salts. Unless the acid solution is excessively weak, there is not usually any formation of rust or basic salt in the presence of air, and the surface of the metal remains bright. The iron is continuously passing into solution, however, with consequent loss in weight.

MEASUREMENT OF CORROSION.

It is customary to express the corrodibilities of different samples of iron in terms of their relative losses in weight under certain well-defined conditions. In the absence of graphitization and pitting, this method is exceedingly valuable and trustworthy; but if either of these phenomena occurs, supplementary data are essential.

For example, a pipe or boiler will leak if perforated by a single rust pit, no matter what weight of metal remains, again, the tensile strength of a pitted or graphitized bar may be locally reduced to a highly dangerous minimum, while the remainder of the bar is sound, In either case

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[1] For convenience, the unqualified word *iron* is used here and in the sequel to denote the various kinds of commercial iron and steel without differentiation.

[2] Rennie, *Min. Proc. Inst., C. E.*, 1845, **4**, 323. Draper, *Chem. News*, 1887, **56**, 251. Durkee, *Amer. Chem. J.*, 1896, **18**, 849. Examples are quoted in Mr. Redgrave's paper, p. 35.

[3] Lidy, *Engineering News*, 1897, **39**, 85.

the loss in weight may be negligibly small and may give no indication whatever of the seriousness of the damage.

Evidently therefore, in addition to recording the losses in weight of various metals upon exposure to corrosive influences, it is eminently desirable to ascertain in detail the extent and depth of any pitting that may have taken place, and whenever possible also the reduction in tensile strength.

ACCELERATION TESTS.

Numerous attempts have been made to determine the relative corrodibilities of various samples of metals by rapid laboratory methods, known as "acceleration tests." A method held in high esteem by manufacturers within recent years consisted in exposing the metals to the action of dilute sulphuric acid for short periods of time, and noting the losses in weight due to solution. It was soon found, however, that the results obtained in this way gave no indication whatever of the relative resistances offered by the metals to corrosion in actual practice. In fact, no reliable acceleration test has yet been discovered. The only satisfactory method lies in exposing the metals to corroding influences under conditions precisely similar to those to which the metals would be exposed in practice. They may then be examined for loss in weight, depth of pitting, etc. To be entirely trustworthy the experiments should be carried out in a series of "field" tests on a large scale. This is admittedly a slow and laborious process; but, in the absence of a better, it is the only one to be recommended.

CHEMICAL COMPOSITION AND CORRODIBILITY.

It is a matter of common knowledge that the addition of small quantities of alloying elements to a relatively pure iron has an altogether disproportionately great influence upon the physical and chemical properties of the metal. Indeed in certain cases, even a trace of the foreign substance exerts a marked effect, phosphorus being a case in point. It is not surprising, therefore, that the susceptibility of iron to corrosion is materially altered in a similar manner.

Carbon.—The influence of carbon upon the corrodibility of iron depends very largely upon whether or not it is combined with the metal. In wrought iron and steel any carbon present is usually in the combined form, and it is now fairly well established that such carbon in general increases the corrodibility of the metal, both in neutral and in acid media.[1] In cast iron the condition of the carbon is largely dependent upon the silicon content, and its effect upon the corrodibility of the metal is thereby complicated.[2]

Chromium, above a certain minimum, tends to reduce the corrodibility of iron in tap water. In salt water its behaviour is unusual. The first effect of the chromium appears to be that of increasing the corrosion, but

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[1] See Chappell, *J. Iron Steel Inst.*, 1912, I. 270. Aitchison, *Trans. Faraday Soc.*, 1916, **11**, 212. Hadfield and Friend, *J. Iron Steel Inst.*, 1916, I. 48.

[2] See p. 82.

further addition of chromium effects a reduction in corrodibility.[1] Toward acids the alloys are eccentric, their resistance varying with the degree of concentration of the acid.[2] Alloys containing a high percentage of chromium are known as "stainless" steel, and are characterised by their remarkable incorrodibility. In a private communication Sir Robert Hadfield informed the Committee that he had recently carried out some experiments with an alloy of iron and chromium which showed considerable resistance to sea-water corrosion. Immersion in sea-water for many weeks has caused little or no effect.

Copper was, for many years, regarded as an injurious element in steel, but several recent researches indicate that cupriferous steels, if low in sulphur, offer a high resistance to corrosion in both neutral and acid media.[3] With 2 per cent. of copper very thorough protection is afforded, the corrodibility being reduced thereby in certain circumstances to 30 per cent.[4] On the other hand, the presence of copper does not appear to protect iron or steel from corrosion by sodium chloride solution, and hence, presumably, from sea-water attack.[5] Further research on this subject might yield valuable information.

Manganese.—The influence of manganese upon the corrodibility of iron has been the subject of no little discussion, but recent work appears to have fairly well established the following conclusions.[6] Increase of the manganese content from $\angle$ 0·2 to approximately 0·7 per cent. slightly increases the corrodibility of the metal in neutral media, such as river or sea water, in the presence of $\angle$ 0·5 per cent. of carbon, whilst it affords a mild protection with higher carbon contents; on the other hand it enormously increases the susceptibility of the metal towards acid attack with all carbon contents ranging from 0·03 to 1·63 per cent. This is a point of considerable commercial importance, since the manganese content of ordinary steels usually lies between 0·3 and 0·7 per cent.

Nickel reduces the corrodibility of iron in all media, provided it is present in sufficient quantity. A minimum of from 2 to 3 per cent. is required to produce an appreciable effect, and upwards of 6 per cent. if the corrodibility is to be reduced to one half.[7] This is disadvantageous in two ways, for not only is the cost of the metal enormously increased, but the physical properties are affected in what is, for most commercial purposes, an undesirable manner.

Phosphorus.—The few experiments that have been carried out with the object of determining the influence of phosphorus in this respect indicate that by increasing its percentage from $\angle$ 0·01 to about 0·85, the

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[1] See Hadfield, *J. Iron Steel Inst.*, 1892, II. 92. Friend, Bentley and West, *ibid.*, 1913, I. 388. Aitchison, *loc. cit.*

[2] Monnartz, *Metallurgie*, 1911, **8**, 161, 193.

[3] Breuil, *J. Iron Steel Inst.*, 1907, II., 1. Walker, *ibid.*, 1911, II., 649. Stead, *ibid*, 1916, I., 72. Buch, *J. Ind. Eng. Chem.*, 1913, **5**, 447.

[4] Stead and Wigham, *J. Iron Steel Inst.*, 1901, II., 1.

[5] Aitchison, *loc. cit.*

[6] Hadfield and Friend, *J. Iron Steel Inst.*, 1916, I., 48.

[7] See Riley, *J. Iron Steel Inst.*, 1889, I., 45, Howe, *ibid.*, 1900, II., 567, Friend, Bentley and West, *ibid.*, 1913, I., 381.

susceptibility of the metal to corrosion in sea-water is reduced by some 30 per cent.[1]

Silicon.—The addition of silicon to iron greatly enhances its resistance to corrosion, and an alloy containing about 20 per cent. of silicon is practically incorrodible both in neutral and in acid media.[2]

Sulphur is always an undesirable element in iron since it tends to oxidise to sulphuric acid, which actively stimulates corrosion.

From the foregoing it is evident that special steels can be prepared which are highly resistant to all kinds of corrosion. For most commercial purposes, however, such steels could not be used, partly because of their high cost, and partly, also, because the alloying elements affect the physical properties of the steel to such an extent that the metal would not be suitable for structural purposes.

CORROSION AND POTENTIAL DIFFERENCE.

Influence of Stress.—When a piece of wrought iron or steel has been subjected to any kind of stress at a particular point, and is then exposed to oxidising influences, it is usually observed that the corrosion is most intense at or near the point of stress. It is largely a matter of circumstance as to whether the strained or unstrained portion is actually the more corrodible. Andrews,[3] for example, found the strained portion to be cathodic to the unstrained, and hence less readily corrodible, whether the stress was tensile, torsional or flexional; Hambuechen,[4] however, obtained an entirely opposite result. The reason for this anomaly appears to lie in differences in the extent of the strain, for such pieces of metal as have been stretched beyond the elastic limit prove more corrodible than any others.[5] But whether it be the strained or the unstrained portion of the metal that is the more corrodible in any special case, the result is much the same, namely that, at the junction of the two areas, corrosion proceeds with increased rapidity, one portion acting as cathode and the other as anode, although the difference of potential is small.[6] Corrosion of this kind is readily observed, for example, in the neighbourhood of punched rivet holes, and at the sheared edges of plates, although in this latter case the removal of the protecting layer of mill scale is not without influence.

Influence of Surface Impurities.—Surface impurities such as cinder and mill scale are apt to lead to serious corrosion in certain circumstances. In the case of aerial structures which are destined to be protected by paint, and exposed only to atmospheric corrosion, it is neither necessary nor advantageous to remove the mill scale previous to painting,[7] since the

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[1] Diegel, *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1900, **5**, 17.

[2] Jouve, *J. Iron Steel Inst.*, 1901, III., 310.

[3] Andrews, *Min. Proc. Inst. C. E.*, 1894, **118**, 356, supported by Walker and Dill, *Proc. Amer. Soc. Testing Materials*, 1907, **7**, 230.

[4] Hambuechen, *Bull. Univ. Wisconsin Engineering Series* 8 (1900).

[5] Burgess, *Trans. Amer. Electrochem. Soc.*, 1908, **13**, 17.

[6] Richards and Behr, *Publication Carnegie Inst., Washington*, 1906.

[7] Friend, *J. Iron Steel Inst., Carnegie Schol. Memoir*, 1918.

scale tends to preserve the underlying metal from attack. This, of course, only applies to relatively thin coats of mill scale, which closely adhere to the metal. But when the metal is destined to be submerged, as in the case of ships, etc., whether painted or not, the presence of scale is likely to cause serious pitting,[1] since the scale is, in the presence of an electrolyte, cathodic to the iron, which latter rapidly corrodes at the point of contact of the two.

If the scale were as elastic and as adhesive to the metal as it is incorrodible, it would form an excellent protective layer, and only the edges of the metal would require attention. But unfortunately the scale is brittle and readily cracks, exposing the underlying metal to attack at a larger number of points. This is well illustrated in the case of boiler plates, the interiors of which frequently corrode in parallel grooves, due to the cracking of the inelastic scale consequent upon the alternating stresses to which the plates are subjected during the working of the boilers.[2]

Contact with Metals.—Iron, when immersed in water or in aqueous solutions, may be preserved from corrosion by being placed in contact with a more highly electropositive metal, such as zinc. The last named, however, undergoes oxidation and requires repeated renewal.[3] This is the principle underlying the protection of iron by galvanising, for which purpose in the U.S.A. alone some 60,000 tons of zinc are annually consumed.

If the galvanising is well done, so that the iron is thoroughly coated with zinc, the iron is immune from corrosion as long as the zinc coating remains intact.

For similar protective purposes lumps of zinc are sometimes placed in boilers, and the corrosion of the iron has thereby been appreciably reduced.

If, however, iron is placed in contact with a more electronegative metal, the latter is preserved from oxidation at the expense of the iron. This is a point of considerable importance to the engineer since, in the construction of steel ships, caissons, etc., the different sections riveted together are liable to vary somewhat in their chemical composition and hence, upon immersion in sea-water, to manifest a difference of potential leading to increased corrosion of the more electropositive parts.

The greater the variation in composition in general the greater is the potential difference, and hence the corrosion. For this reason portions of the structure patched or strengthened at a later date frequently corrode more rapidly, since the quality of the original metal cannot be exactly matched.

In certain cases where only portions of a steel structure are exposed to very corrosive influences, it might appear advisable to employ in the exposed areas some specially resistant alloy, such as nickel steel. The

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[1] Barnaby, *Min. Proc. Inst. C. E.*, 1881, **65,** 104. *Trans. Inst. Naval Architects*, 1879, **20,** 225. White, *J. Iron Steel Inst.*, 1881, I., 68.

[2] Frémont and Osmond, *Revue Metallurgie*, 1905, **2**, 775.

[3] E. Davy, *British Assoc. Reports*, 1835.

junction of this, however, with the ordinary metal would, for the reason given above, tend to corrode more rapidly, although it is possible that this might be negatived by separating the metals previous to riveting with some non-conducting material. Experiments on this point would probably lead to interesting results.

THE ACTION OF SEA-WATER UPON IRON.

The action of aqueous solutions of inorganic salts upon iron in the presence of air depends upon the concentration and the temperature Thus laboratory experiments indicate that a saturated solution of common salt is considerably less corrosive than tap water at the same temperature.[1] Again, a 3 per cent. solution of common salt is more corrosive than tap water at 10° C., but as the temperature is raised it becomes relatively less corrosive, until at 21° C. the solution is less corrosive than fresh water at the same temperature. Now sea-water contains some 3 per cent of sodium chloride, and since at the mouths of tidal rivers it becomes considerably diluted it is instructive to determine the relative corrosivity of sea-water at various temperatures and at different dilutions. Generally speaking, at 18° C. and above, all dilutions of sea-water are less corrosive than fresh water, but at lower temperatures they are more corrosive. At 11° C. undiluted sea-water is considerably more corrosive than fresh water. At 13° C. the two waters are equally corrosive, whilst at higher temperatures sea-water is less corrosive than fresh water.

These observations are of particular interest to marine engineers, and a series of field tests on the subject would yield valuable results. In the western part of the Tropical Pacific a temperature of 32° C. is often attained, and in the Red Sea and Persian Gulf the waters have reached 34·4° C. and 35·5° C. respectively. Such waters would thus be less corrosive than river waters at the same temperatures. In the Arctic Ocean, on the other hand, the temperature often falls below 0° C., and the sea-water is thus more corrosive, whilst in temperate climes the relative corrosivity fluctuates according as the temperature lies above or below 13° C.

THE PRESERVATIVE ACTION OF ALKALIES.

Although the merest traces of alkali will protect the purer forms of iron from corrosion in distilled water, a certain minimum concentration of alkali is essential for this purpose, if foreign substances such as carbon dioxide and inorganic salts can gain access to the solution. For example, wrought iron will remain bright in a 1 per cent. solution of potassium hydroxide for an indefinite time, but upon addition of potassium chloride corrosion readily takes place. It is possible, however, to raise the concentration of the alkali to a point at which corrosion is entirely prevented, no matter how much chloride may be added.

When this minimum of alkali is not present the rusting which takes place is characterised by being localised at numerous points; here small masses of oxide accumulate on the metallic surface and these, when scraped

[1] *Adie, Min. Proc. Inst. C. E.*, 1845, **4**, 323.

away, betray the presence of holes or pits, often eating deeply into the solid metal. Most probably the pitting originates at points where traces of impurity are present; nevertheless, the purest forms of iron are subject to serious attack under the foregoing conditions.

This is an aspect of the subject which demands the thoughtful attention of boiler engineers, since weakly alkaline feed waters are sure to produce trouble. The remedy seems to lie in increasing the alkalinity to the point at which corrosion becomes impossible.[1]

RELATIVE CORRODIBILITIES OF IRON AND STEEL.

The question as to which is the more corrodible, wrought iron or steel, has been the subject of much discussion. Special steels must, of course, be ruled out, since it is possible, by addition of certain alloying elements to reduce their corrodibilities to a negligibly small quantity.

In 1902 Rudeloff[2] compared the relative losses in weight of two wrought irons and two steels after exposure to various neutral corroding media, such as dry air, the weather, smoke, ditch-water and sea-water, respectively. Plates of two thicknesses, namely 0·5 cm. and 0·075 cm. of all four metals were experimented with, and interesting variations were observed in their behaviour.

In the case of thin plates, although the individual specimens showed considerable variation amongst themselves, the mean corrodibilities of the two wrought irons and the two steels were numerically almost identical, namely:—

Wrought iron	100
Steel	106

With the thicker plates the steels showed to less advantage, the results being:—

Wrought iron	100
Steel	131

the thick steels thus losing 31 per cent. more in weight than the thick wrought irons.

In 1908 Howe and Stoughton,[3] in a somewhat similar series of tests, found that, after 2 years of exposure to corroding influences, wrought iron and steel lost in weight relatively as follows:—

Wrought iron	100
Steel	105

After an exposure of 8 years, however, the wrought irons proved markedly superior, thus:—

Wrought iron	100
Steel	133

As regards loss in weight, therefore, the balance inclines favourably

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[1] Lyon, *Iron Age*, 1914, **93**, 1005. *J. Amer. Soc. Naval Engineers*, 1912, **24**, 845. Friend, *J. Iron Steel Inst., Carnegie Scol. Memoir*, 1911.

[2] Rudeloff, *Mitteilungen aus dem königlichen technischen Versuchsanstalten*, Berlin, 1902, **20**, 83.

[3] Howe and Stoughton, *Proc. Amer. Soc. Testing Materials*, 1908, **8**, 247.

towards wrought iron. But loss in weight is not the only feature to be considered. Of equal importance is the extent and depth of pitting. When this is carefully measured the advantage appears to lie with the steel. Thus examination[1] of twenty-one samples of metal plates after prolonged exposure to hot, aerated sea-water gave the following results :—

	Mean depth of pitting.
Wrought iron	0·028 inch.
Steel	0·017 „

Here the advantage lies most decidedly with the steel. An examination[1] in 1912 of sixty-four iron and steel service pipes in certain water systems in New England revealed the following interesting facts :—

Wrought iron corroded more than steel	20 cases.
Steel corroded more than wrought iron	18 „
Both metals equally corroded	9 „
Corrosion negligibly small	17 „
	64

The foregoing results indicate that the question as to whether wrought iron is or is not more corrodible than steel cannot be answered by a mere affirmative or negative. The standard by which corrosion is to be judged and the kind of corroding medium to be employed must be stated.

For some purposes wrought iron is undoubtedly better than steel; for other purposes the reverse is true; and for yet others there is no appreciable difference.

CORROSION OF CAST IRON.

Owing to the complexity of its composition the problem of the corrosion of cast iron is intricate.

As has already been mentioned, the metal is particularly liable to graphitization, in which case it may suffer serious diminution in strength without undergoing any appreciable alteration in external appearance.

Variation in the silicon content from 1·24 to 2·28 per cent. appears to be practically without influence upon the corrodibility of grey cast iron, both in acid and in neutral media, provided the amounts of graphitic and combined carbon remain constant.[2] Apparently no data have been published showing the effect of varying the proportion of graphitic and combined carbon, although Mallet observed that the surface of chilled cast iron tends to corrode more rapidly than that of the same quality metal cast in green sand.

Further research on this branch of the subject would be welcomed.

In neutral corroding media, grey cast iron with its skin removed is apparently rather less corroded by neutral media than ordinary steel. If the "skin" of the cast iron is allowed to remain on, however, the metal is very much more resistant to corrosion.[3]

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[1] Walker, *J. New England Water Works Assoc.* 1912, **26**, No. 1.
[2] Friend and Marshall, *J. Iron Steel Inst.*, 1913, I., 382.
[3] Thwaites, *ibid.*, 1880, II., 267.

SPECIAL REPORTS FROM CORRESPONDING MEMBERS.

SECTION I.

BRITISH PORTS AND HARBOURS.

The following papers have been received from the Corresponding Members with regard to the home ports, and they are printed in the above order.

BELFAST HARBOUR.

By T. S. GILBERT, M.Inst.C.E.

Timber Structures.—The Queen's Quay is a timber wharf, constructed in the years 1875–1877, and consists of greenheart, pitch pine, American rock elm, and Quebec red pine, but mainly of pitch pine in piles, joists, decking, wales, &c. These timbers are bolted together with 1-inch

diameter iron bolts, and the sheeting and main piles are tied back to stay piles with round iron tension rods 2½ inches diameter.

All the principal timber was specified to be creosoted with 8 lbs. of oil to the cubic foot of timber, but it is doubtful if the heavier pitch pine would take this amount.

Owing to the rearrangement of the cranes and tramways, the timber and iron were carefully examined recently with a view to determine whether this quay would stand the increased loads rendered necessary by the addition of electrical cranes, and in order to strengthen the work where it was considered advisable. It was found that, on the whole, the timber was in an excellent state of preservation—in many places it was in as sound and sharp a condition as the day it was put there, more than forty years ago—and practically no traces of the operations of marine organisms were in evidence. It should, however, be noted that the timber here is specially well situated, so far as resistance to such organisms are concerned, as it is the innermost quay at the harbour, and the water is generally very dirty, and contains mud as well as quantities of sewage and vegetable matter.

The analysis, marked "A," of a sample of water taken, where shown on plan, see Fig. 1, at the south end of this quay at approximately half tide, will give some indication of the average condition of the water; but, of course, at high tide it is more saline, and at low tide much less so, especially after a "fresh" in the river.

The principal deterioration of the materials comprised in this quay with which we have to contend is the eating away of the iron bolts, &c., and the rotting of the surface timber, the latter being principally due to the percolation of rain water through the joints, &c., in the quay decking, thus causing damage to certain portions of the structure, such as the joining of the decking with the joists. Recently the greater number of bolts both at high and low water have had to be renewed, owing to the extent to which they had become deteriorated—in some cases they were almost eaten through.

With regard to the life of this quay it is difficult to assign a figure to it, but I think, with care and due regard to the necessity of periodical examination and renewal of the iron bolts, &c., and in view of its present condition after 40 years' wear, there is no reason why it should not be in existence 100 years from the date of construction.

The Albert Quay, built in the years 1872–1875, is similar to the Queen's Quay in design and method of construction, but it is not at present in such good condition. This is mainly due to the fact that the strata on which it is founded differ from the Queen's Quay foundation, and on this account greater strain is thrown on the back of the timber-work. Heavy loads of coal are also carried on the ground behind the quay, and this has caused local movement at different parts, with the result that the quay is out of line in places. This is not so to any appreciable extent, so far as its efficiency as a quay is concerned. The timberwork is in much the same state as that already indicated in connection with the Queen's Quay, and the deterioration observed in the materials is of a similar nature, qualified by the fact that the condition

of the quay as a whole is not so good, owing to the causes above referred to. In this case also it has been found necessary to renew practically all of the 1-inch diameter iron bolts between the levels of high and low water, owing to the extent to which they have become deteriorated. In some instances the bolts referred to have been reduced to a mere thread.

The Alexandra Wharf was constructed in the year 1899–1900, and is of much the same design as the quays just referred to. It has suffered little from sea organisms, but the bolts are in bad condition, and the same may be said of No. 3 Quay, Musgrave Channel, built in the year 1903, and in many respects similar in design and method of construction to the Queen's and Albert Quays.

As will be seen from the plan and analysis, the water at this spot is cleaner and more saline than at any other of the quays on the river, as it is more exposed to the salt water of the lough than to the fresh water of the river.

The pitch pine of which it was principally constructed was creosoted on the "time and pressure" system, the original method of inserting a certain fixed number of pounds of creosote oil to the cubic foot of timber having been found impracticable, owing to the fact that some of the best and hardest of the timber would not take the specified amount. Notwithstanding the care taken with the creosoting, this quay has begun to show signs of the ravages of sea-worms, &c.

The remaining timber wharves and jetties at this port show no signs of serious deterioration, and have apparently a long period of useful life before them. It may be stated generally that previous to the war creosoted pitch pine was the most satisfactory and economical material at our disposal for the construction of wharves, jetties, &c., but now, owing to high prices and difficulty of procuring timber, and the fact that our new quays, &c., are developing seawards, with the consequent reduction in the life of the timberwork, it has become probable that reinforced concrete, or concrete in bulk, will in future be found a more lasting and economical method of construction at this port.

I should like to point out generally that while we use greenheart to some extent in our timber wharves and jetties at Belfast, it has not been adopted on account of its practical immunity in these waters from the attacks of marine organisms, but it has been used in a few places where we required extra strength, such as in the case of mooring pawl piles. We have, however, used it instead of creosoted pitch pine at No. 1 Lighthouse, which is situated in deep water about five miles out to sea from the docks and quays. In this position we find greenheart suffers little or no deterioration from the effects of its exposure to the sea during a period of nearly thirty years, whereas experience leads us to believe that here creosoted pitch pine would suffer so much as to render its use uneconomical.

Although it is outside the jurisdiction of Belfast Harbour, I may mention that in the cleaner and more saline waters of Larne Harbour, co. Antrim, and Bangor, co. Down, the attacks of the *Teredo navalis* and other marine organisms assume much more serious proportions than at Belfast Harbour. In neither of these two places, I understand, does creosoted pitch pine offer enough resistance to justify its use, and at

Larne Harbour I have noticed that the inroads on square greenheart piles have been considerable; in some cases the square section of a 12-inch by 12-inch pile at about the level of low-water has been reduced to a round section of about 9 inches diameter. I understand that practically all the piles of the quays at Larne Harbour are of square greenheart timber, untreated in any way.

A small timber pier at Bangor, co. Down, which came under my observation recently, was built about the year 1896, and constructed of creosoted pitch pine. This pier had a short time ago to undergo extensive repairs.

It was discovered that some of the 12-inch by 12-inch piles were eaten completely through, and apparently they suffered most severely where they entered the sand, which was about the level of low-water. The upper portions of the timberwork were in fairly good condition, whilst that part of the pile which was embedded in the sand was found to be in an excellent state of preservation.

Through the courtesy of the owner of this pier I am able to submit a sample of timber, marked No. 3, which will give some idea of the ravages of sea organisms on creosoted pitch pine in these waters. This is a section of a 12-inch by 12-inch pile after being exposed for about 20 years. From the above it would appear that the maximum life of creosoted pitch pine at this point of the coast would not be more than 20 years.

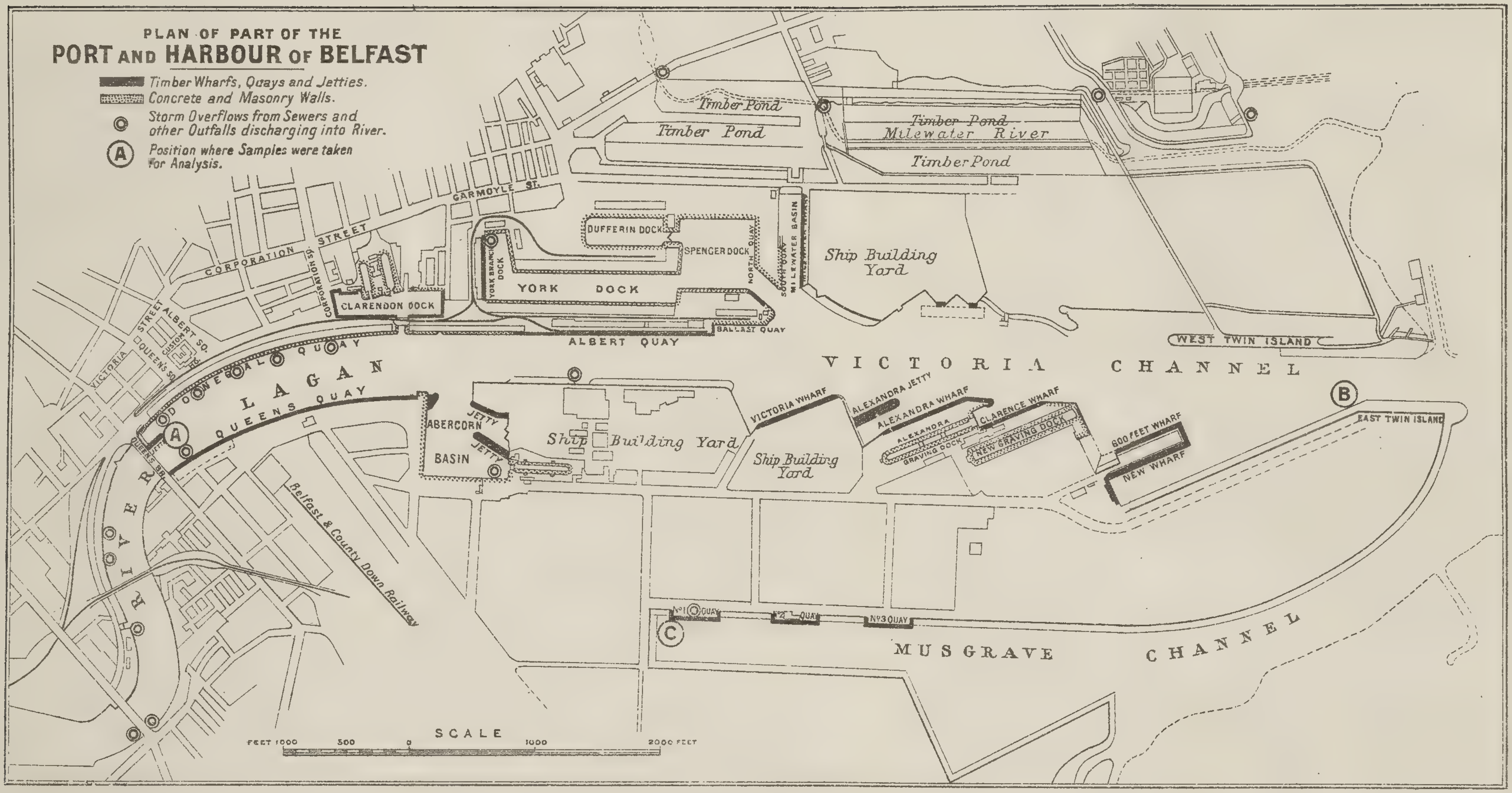
Concrete Structures.—The longest recorded history of concrete in bulk at this port is that of the Alexandra Graving Dock, constructed in the years 1885–1889.

The main concrete in this dock consisted of 2½ parts whinstone metal, 3½ parts of gravel from the foreshore at Carrickfergus, 2 parts sand, and 1 part cement or hydraulic lime; while the facing concrete was composed of 3 parts gravel, 1 part sand, and 1 part cement. A considerable portion of the facing cement was not carried up at the same time as the main bulk, and the work in some places was not satisfactorily executed, with the result that defects in the concrete manifested themselves shortly after the dock was finished, generally in the form of large cracks or fissures. These apertures allowed the salt water, with which the backing was saturated, to pass into the dock through the walls and floor, injuring the concrete in their immediate neighbourhood. At one time this involved considerable extra pumping to deal with the water which accumulated in the dock through these defects.

In consequence of a serious accident in the year 1911, which had, however, no connection with the defects just mentioned, it became necessary to sink a caisson right through the concrete into the foundation of the dock, involving a cutting about 6 feet in width across the dock. Contrary to expectations, and notwithstanding the cracks referred to, the greater part of the concrete exposed, or which had to be removed, was found to be surprisingly good and sound, and required a considerable amount of blasting to remove it.

Generally, with regard to stone and concrete structures exposed to the action of the waters of Belfast Harbour, there is no evidence of any deterioration of the materials due to that cause, the above example is a

FIG. 1.


PLAN OF PART OF THE
PORT AND HARBOUR OF BELFAST
Timber Wharfs, Quays and Jetties.
Concrete and Masonry Walls.
Storm Overflows from Sewers and other Outfalls discharging into River.
Position where Samples were taken for Analysis.
Timber Pond
Timber Pond
Timber Pond
Milewater River
Timber Pond
GARMOYLE ST.
CORPORATION STREET
CORPORATION SQ.
DUFFERIN DOCK
SPENCER DOCK
YORK BRANCH DOCK
YORK DOCK
CLARENDON DOCK
NORTH QUAY
SOUTH QUAY
MILEWATER BASIN
MILEWATER WHARF
Ship Building Yard
BALLAST QUAY
ALBERT QUAY
WEST TWIN ISLAND
ALBERT SQ.
VICTORIA STREET
QUEENS SQ.
CUSTOM HOUSE
DONEGALL QUAY
RIVER LAGAN
QUEENS QUAY
QUEENS BR.
VICTORIA CHANNEL
ABERCORN BASIN
JETTY
JETTY
Ship Building Yard
VICTORIA WHARF
Ship Building Yard
ALEXANDRA JETTY
ALEXANDRA WHARF
ALEXANDRA GRAVING DOCK
CLARENCE WHARF
NEW GRAVING DOCK
800 FEET WHARF
NEW WHARF
EAST TWIN ISLAND
Belfast & County Down Railway
Nº1 QUAY
Nº2 QUAY
Nº3 QUAY
MUSGRAVE CHANNEL
SCALE
FEET 1000
500
0
1000
2000 FEET

special case where the concrete was under pressure, and in some places the workmanship was not very reliable. Properly proportioned concrete, well built into carefully designed walls, would, I consider, be quite immune from any evil effects due to exposure to the waters of this port.

Copy of Result of Analysis of Sample of Water taken at Queen's Quay, Marked "A."

Chlorine	1,123 grains per gallon
,, equivalent to common salt	1,851 ,, ,,
Total solid residue	2,589 ,, ,,
Free or saline ammonia	0·080 parts per 100,000
Albuminoid ammonia	0·018 ,, 100,000

Copy of Result of Analysis of Sample of Water taken at East Twin Island, Marked "B."

Chlorine	1,250 grains per gallon
,, equivalent to common salt	2,061 ,, ,,
Total solid residue	2,826 ,, ,,
Free or saline ammonia	0·056 parts per 100,000
Albuminoid ammonia	0·020 ,, 100,000

Copy of Result of Analysis of Sample of Water taken in Musgrave Channel, Marked "C."

Chlorine	1,278 grains per gallon
,, equivalent to common salt	2,107 ,, ,,
Total solid residue	2,776 ,, ,,
Free or saline ammonia	0·056 parts per 100,000
Albuminoid ammonia	0·028 ,, 100,000

Copy of Result of Analysis of Sample of Water taken at Outer Lighthouse in Open Sea.

Chlorine	1,334 grains per gallon
,, equivalent to common salt	2,199 ,, ,,
Total solid residue	2,806 ,, ,,
Free or saline ammonia	0·016 parts per 100,000
Albuminoid ammonia	0·016 ,, 100,000

H.M. DOCKYARD, CHATHAM.

By SIR THOMAS SIMS, C.B., M.Inst.C.E., Member of the Special Committee.

As no continuous records have been kept, it is feared that experience at Chatham will not be of much value as a contribution to a consideration of the deterioration of structures exposed to sea-action.

Chatham lies on a tidal estuary, and is washed by strong tidal currents; the natural salinity of sea-water is, as a rule, little affected by the comparatively small quantity of upland water discharged. The tidal

range is about 18 feet on spring tides. The water is heavily charged with a fine muddy silt, which is freely deposited in all backwaters and eddies.

Dock walls have been constructed partly in concrete and partly in brickwork. The walls at the locks were built in 1870 of concrete, composed of one part cement to twelve parts of shingle for the mass, faced with concrete composed of one of cement to six of slag and sand. This concrete is in fairly good condition except at junction surfaces where the day's work appears to have stopped. These surfaces are in many cases quite discernible, dividing the mass into blocks. The face of the wall has in several places been considerably eroded, some of these excavations being 1 or 2 inches deep. Such areas are rather more noticeable below high water, but the difference is by no means marked. The concrete backing in walls has on several occasions, when opened out recently, proved to be little better than loose gravel, and could readily be moved with pick and shovel. It is not apparent whether this is due to initial lack of cement or whether in porous concrete the cement has been destroyed by the action of salt water.

Brickwork has been largely used elsewhere in the river and basin walls. The bricks were made locally, and were apparently of very uneven quality. They were laid in mortar consisting of three parts of sand to one of Portland cement, and were built about 1870. The brickface work has in many places crumbled away over large areas, under exposure to tide and weather, and has been patched from time to time with hard stock bricks. These show little deterioration in a period of twenty years. Where not exposed to the atmosphere and tide, brickwork of local, convict-made bricks in mortar as described has proved exceedingly tough, and harder to cut out than present-day concrete—one cement to eight of Thames ballast—made only a few years ago.

There is no ferro-concrete work of any magnitude at Chatham, a small jetty, a partly finished pier, and a crane gantry, all comparatively new, being the sum total. There is no deterioration to report.

Of timber structures, there are several jetties on the river, one or two being permanent, and others of a more temporary character. Creosoted pitch pine has been used in the more permanent structures. Piling of this material driven into silt, at a landing place in 1904, is now becoming unsafe owing to the attack by teredo.

Similar piling in a jetty constructed by the military in 1912 is still sound, but worm holes can be traced in it to a depth of $1\frac{1}{2}$ inches. Untreated pitch pine piles driven in the same vicinity in 1912 have been badly attacked by teredo; a sample from a pile, 12 inches by $13\frac{1}{2}$ inches, now in the office, being reduced to an effective diameter of less than 9 inches. Piling in mud rising above low-water level is found to be less liable to attack by worm; e.g. the piling of a temporary jetty, built about 1902, of untreated pitch pine, is practically quite sound, only two piles out of 200 showing traces of attack. These piles are immersed about three or four hours per tide.

The attack is most intense just below low-water mark, especially when the depth of water is moderate. Untreated pitch pine piles driven in the

river have suffered badly from 1 foot below to 3 feet above mud level, i.e., to low-water level. They were protected a few years ago by sheaths of reinforced concrete, and this method has proved fairly satisfactory. A railway jetty has been treated in a similar manner.

Fender piles on the river frontage of the Dockyard have been made of Dantzic fir, Oregon pine, pitch pine, etc., sometimes creosoted, sometimes treated with various superficially applied preservative compounds, such as jodelite, green oil, etc., but generally untreated. Most of these timbers are dry at low water, but all have suffered a good deal from teredo attack to about 3 feet above mud level.

Of iron and steel structures two crane gantries in a dock and a pier in the river are the principal items. Corrosion on the former, a wrought iron structure, dating from 1875, has been very marked. Various protective coatings have been used, such as red oxide and graphite paint, bitumastic solution, tar, etc. None of these have been found effective, except for short periods, and experience seems to indicate that a coating of refined tar and lime, applied annually at least, is the most economical and effective preservative.

The steel plate piles driven in 1899 at the latter pier appear to suffer less below than above high-water mark, and are generally in good condition.

DOVER.

By M. F. G. WILSON, M.Inst.C.E., Member of the Special Committee.

At the Admiralty Harbour Works, Dover, where the writer was Superintending Engineer, Tasmanian blue gum was largely used for piles in connection with the temporary stagings. Many of the piles were 100 feet and upwards in length, and from 16 inches to 20 inches square. The piles were taken up and re-driven thrice or four times, as the stagings were extended, being in use altogether from three to eight years, some no doubt longer. They were ultimately found to have been very little affected by worm action, except upon the outer surface, which was attacked to a moderate depth by limnoria. After having been used as already stated for temporary stage piles, the outer portion, where worm action had taken place, was sawn off, and the timber was used in the construction of a permanent landing-stage for ocean liners. Oregon pine, which was also used to a limited extent for staging piles, was found to be slightly attacked by teredo, after being two years in the water.

Some years ago, when at Dover, the writer's attention was called to the use of trass in connection with Portland cement, as having the effect of rendering the resultant concrete more watertight. Trass is a clayey or siliceous material of volcanic origin, containing a high proportion of silica, and it has been claimed that the addition of trass to Portland cement has a beneficial effect, inasmuch as the siliceous matter of the trass combines with the lime set free from Portland cement during hydration, thereby rendering it cementitious, and the resulting concrete becomes less pervious to water than it would have been without the addition of the trass. It

has apparently been used to a considerable extent on the Continent, but the writer has no personal knowledge of its having been specially used in connection with reinforced concrete work. The cost of trass is stated to be somewhat less than Portland cement, and the results of some experiments made in 1900 on mixtures of trass in different proportions with lime and with Portland cement were quite satisfactory, so far as tensile strength was concerned, but the question of watertightness was not dealt with.

In 1905, when at Dover, the writer commenced a series of experiments in this direction, but he was unable to complete them. So far as he had proceeded, the tests went to show that Portland cement could be replaced to the extent of between 10 and 15 per cent. by trass without loss of strength, a result which would be satisfactory from the point of view of cost. It would seem to be very well worth while to arrange, where opportunity occurs, for a series of experiments to be made with mixtures of trass or other material with Portland cement, with a view to ascertaining whether a concrete can be obtained which, with ordinary care in mixing, is in itself watertight, without subsequent coating or other treatment.

THE PORT OF DUBLIN.

By Sir JOHN PURSER GRIFFITH, M.A.I., Member of the Special Committee, and JOHN WILLIAM GRIFFITH, M.A., B.A.I.

Timber.—The experience in the Port of Dublin of the effect of sea water on timber structures extends back to the first half of the eighteenth century. The construction of the jetty on the south side of the channel from the Bar to the City was begun early in the eighteenth century. (See Chart of Dublin Bay, Fig. 2.) The portion to the eastward of the Pigeon House consisted of oak piling with hurdles filled in with stone. This was begun in 1717, and reports show that by 1730 the destructive action of the sea-worms was causing anxiety as to the safety of the work. (See A on Plan.) By the middle of the century we find steps taken to replace these timber structures with masonry. It is evident that from the experience gained in early days of the destructive action of the marine worms the engineers in charge of the port determined to adopt masonry instead of timber in all the permanent works of the port.

Towards the middle of the nineteenth century timber wharves were constructed along the north and south quays to provide increased depth of berthage. (See B on Plan.) These were considered as merely temporary expedients until the quay walls were rebuilt. The experience gained was that in the upper portions of the harbour, polluted by sewage, westward of C, the timber remained uninjured by worms, while at the point D, immediately to the eastward, the worms were active. In the North Wall Basin (now called the Alexandra Basin) where the sea-water was uncontaminated by sewage the destructive action of the marine worms was very rapid, until the year 1899, when petroleum storage was intro-

duced into the Port of Dublin, and the oil was imported in tank vessels. The leakage of oil into the harbour during the discharge of the vessels has apparently put an end to the attacks on the timber works in the basin.

The principal timber used in Dublin Harbour was Memel and pitch pine. In some instances attempts were made to protect the piles from the worms by creosoting. As a rule, however, creosoting by the Bethel process was only superficial, and frequently the worms attacked the timber through bolt holes, thus reaching the uncreosoted portion of the timber. Thorough creosoting, such as can be done by high-temperature creosoting,[1] is costly, in consequence of the large quantity of creosote absorbed, and raises the price of Memel or pitch pine to a point at which it would pay to use hard wood, such as greenheart. Piles have also been protected with Muntz metal like the bottom of a timber ship, and, in the case of a timber lighthouse, nails with very large heads, about 1 inch square, were used. (See E on Plan.) Even in spite of these nails the worms got into the interior of the piles and ate the timber away, leaving a shell of nails.

Cast Iron.—The experience of the action of sea-water on cast iron in the Port of Dublin confirms what has already been ascertained in various parts of the world, and what has been recorded in the early "Transactions of the Institution of Civil Engineers."

As far back as the year 1847, by the advice of the late Sir William Cubitt, cast-iron piling was used in the face of the lower portion of the Custom House Quay-wall, which was rebuilt under his advice. (See F on Plan.) The cast-iron piling is similar to that described in Mr. M. A. Borthwick's "Memoir on Iron Piles," published in Volume 1 of the "Transactions of the Institution of Civil Engineers," where the action of sea-water on cast iron is also referred to.

It the case of the Custom House Quay piling the cast iron has been converted into graphite, but the piling is still intact so far as form is concerned, except where injured by the abrasion of ships. The action of the air has not disintegrated the piles, and this appears to be due to the piling being always kept wet by the tide.

Another striking example of the effect of sea-water on iron was in the case of a large quantity of cast-iron cannon balls and bar-shots dredged up during the straightening of the sea approach channel into Dublin. (See G on Plan.) The cannon balls were found buried at a considerable depth in the sand amongst the wreckage of a vessel. When dredged these cannon balls were as perfect in form as the day they were made, the moulding marks being visible and sharply defined. When dried the absorption of air led to their disintegration, as the surface burst off in layers like an onion. This continued for a long time, until the castings were reduced to powder. There is no doubt that if the cannon balls had been kept under water and protected from the air, although converted into graphite, they would have retained their original size and shape.

Masonry or Concrete Structures.—The destructive action of sea-water on the mortar joints of masonry was described by the late Dr. B. B. Stoney in a paper read by him before the Institution of Civil Engineers of Ireland

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[1] See papers by J. P. Griffith, vol. 20 and vol. 24, Transactions Inst. C.E.I.

in 1862.[1] In this case the mortar was made with lime, and was used in the construction of the sea-wall built between 1748 and 1785 bounding the Pigeon House road. (See H on Plan.) Several breaches were made by the sea in this wall and the mortar was found to have been converted into a soft putty. On analysis it was discovered that the magnesia in the salt water had replaced the lime.

This action of sea-water on lime had been noticed by Vicat, and is referred to by several writers. It is mentioned here because it is now recognised that sea-water has a similar effect on Portland cement mortar or concrete, if the latter is not impermeable and if the water can percolate through the concrete.

This led to the practice in Dublin of avoiding as far as possible the use of mass concrete, deposited through water, and of employing in preference air-dried block work. In some cases mass concrete was so deposited. These were, however, exceptional, and were carried out under circumstances which precluded the percolation of sea-water through the concrete, or its superficial injury by wave or current action. The chief precautions taken were that the concrete so deposited should be mixed with sufficient water to make it thoroughly plastic, and that it should be lowered to its bed in boxes of the largest possible capacity available for the work.

Where concrete has been used in positions exposed to sea-water under pressure, as, for instance, in subways constructed below tide level, or in the floor and sides of the pump wells of the graving dock, no attempt has been made to make the concrete impervious by increasing the proportion of the cement used, but a much more efficacious method has been adopted by the insertion of a thin layer of asphalte either within the mass of concrete or else on the outer or pressure side.

This is a most satisfactory and cheap method of obtaining impermeability in such a critical situation as the floor of a graving dock. The floor can then be made of a comparatively poor concrete and the asphalte layer guards against percolation, either through the concrete, owing to cracks due to settlement or contraction, or through structural joints in the floor.

Concrete Blocks.—The experience in Dublin Harbour of the use of concrete block work, where the blocks have been air-dried before immersion, has been extremely satisfactory. No failure from decomposition has taken place. The exposure of the blocks to the air appears to have sealed the pores of the concrete and put a stop to percolation. The present condition of the protective works around the base of Poolbeg Lighthouse at the entrance to Dublin Harbour, consisting of a number of 140-ton blocks deposited some forty years ago (see J on Plan, and Plate II.) proves that blocks which were built high and dry before being brought down and deposited more than three miles from the building yard, are in a better condition now than any of the blocks which were built *in situ* by tidal work. The edges of the transported blocks are in most cases as sharp as when brought down and the surfaces of the blocks

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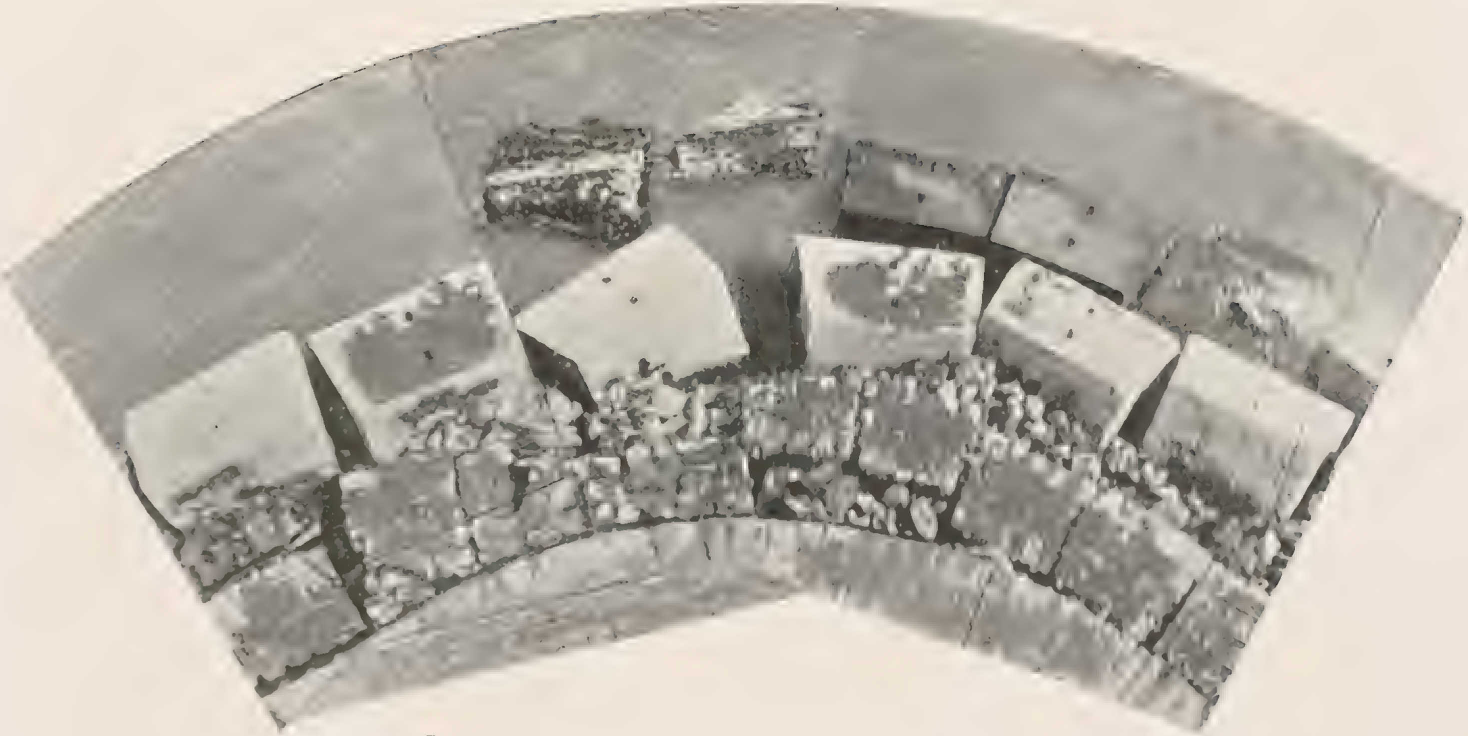
[1] See vol. 7 Trans. Inst., C.E.I.



Concrete Blocks round the Base of Poolbeg Lighthouse.

View from balcony of the lighthouse.

FIG. 2.

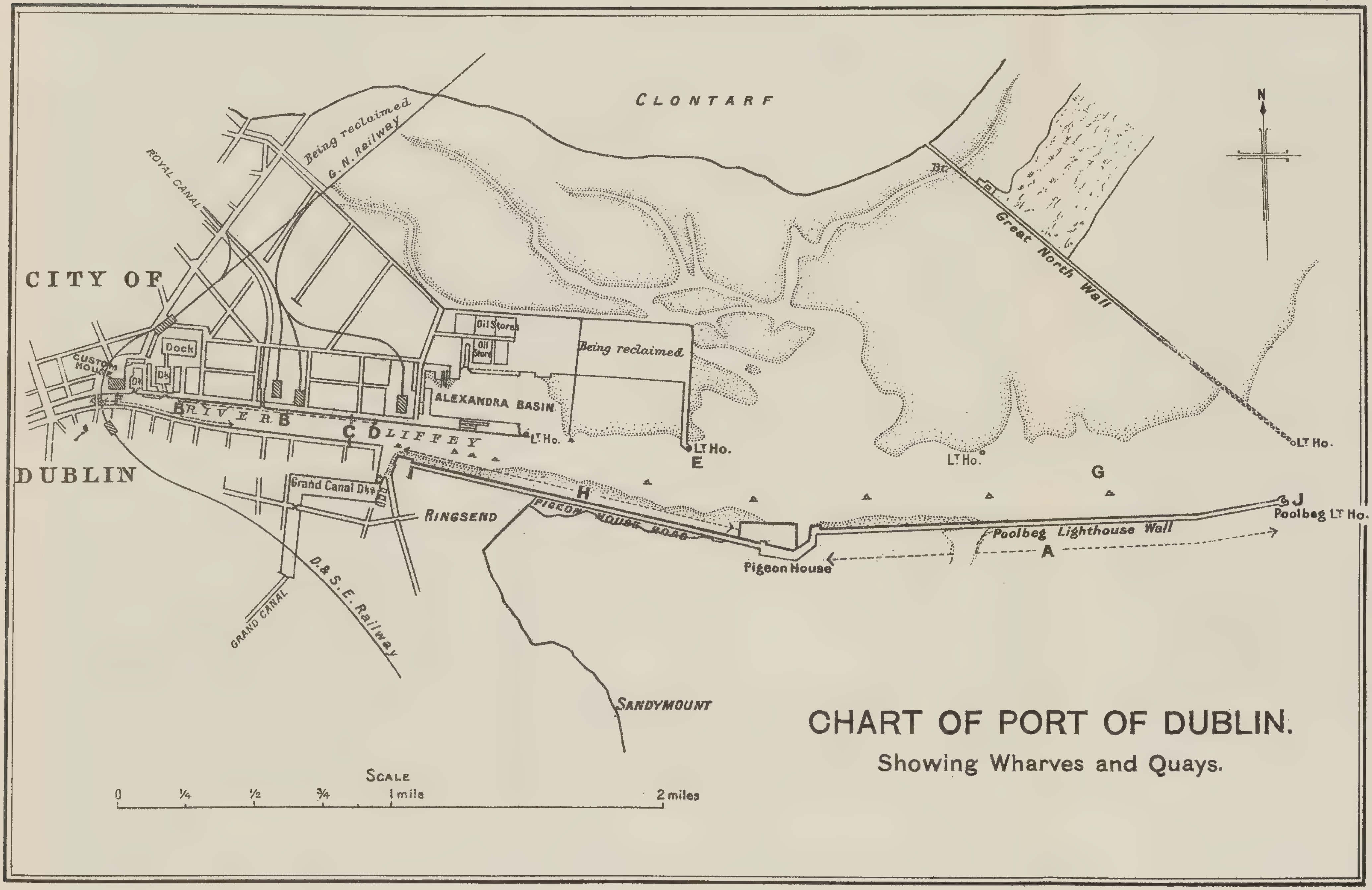


CHART OF PORT OF DUBLIN.

Showing Wharves and Quays.

are uninjured, although laid in one of the most exposed situations in Dublin Bay.

The chart, Fig. 2, which accompanies this memorandum indicates the positions of the several works referred to therein. The photograph of the concrete blocks around the base of Poolbeg Lighthouse, Plate II., shows the present condition of the blocks.

There is a Paper by the late Mr. Bernard Mullins in Volume 2 of the "Transactions of the Institution of Civil Engineers of Ireland," "On boring animals in connection with structures exposed to the sea." It contains the experience and information at the disposal of Irish engineers up to the year 1847, and is valuable.

FLEETWOOD.

By D. C. RATTRAY, M. Inst. C.E.

Fleetwood is situated on the north-west coast of Lancashire near the mouth, and on the west side, of the river Wyre, which issues into Morecambe Bay. The L.W.O.S.T., also the zero of the harbour gauge, is 12·44 feet below Ordnance Datum. The ordinary spring tides have a range of about 27½ feet and the neap tides of about 20½ feet.

The accompanying illustration, Fig. 3, shows the River Channel, Harbour and Docks. The works where inspection and investigation has recently been made for the purposes of this report are marked A, B, C, D, E, F, G, H, J, K, L.

Wyre Lighthouse marked A. on Plan.—The structure of the present lighthouse, erected in 1872, consists of Mitchell's cast iron screw piles to a level of 12 inches below L.W.O.S.T. and on the top of these, fitted into square sockets, are pitch pine timber posts 14 inches square at the base braced by horizontal and diagonal wrought-iron tie rods which support the timber decking at a level of 48 feet above L.W.O.S.T. on which the lighthouse is constructed. These timber posts for a height up to about 10 feet above L.W.O.S.T. were first tarred, then covered with felt on the wet tar, and finally sheathed with lead fastened to the timbers with copper nails. The wrought-iron tie rods and the timber uprights are carefully cleaned and afterwards coated with gas tar every year. These precautions have prevented any damage to the structure either from the action of the sea-water or from sea-organisms. The structure is in sea-water and is not affected by fresh water or sewage.

Long Groyne marked B. on Plan.—This structure, constructed in 1890/5, is approximately 715 yards in length and consists of 12 inches by 12 inches pitch pine piles, about 5 feet centres, with sheeting, extending to about 4 feet above ground level, of 3 inch spruce deals attached to the piles by means of wrought-iron spikes. These timbers are not subjected to any preservative process. The piles have been attacked by sea-organisms to a height of about 10 feet above L.W.O.S.T., and in some cases the piles, originally 12 inches × 12 inches are now only about 10½ inches × 10½ inches. The spruce planking has been attacked to a much greater extent than the

pitch pine piles; at some places it is now only about one-half the original thickness of the planks. The wrought-iron spikes fastening the planks to the piles are, where exposed, corroded by the action of the sea-water. No reliable information as to where the timber came from is now available.

Fleetwood Harbour Pier.—The north end of the Pier, known as the Isle of Man Berth, marked C. on the Plan, was constructed in 1890/4. The structure consists of pitch pine piles, 15 inches square, and cross bracings. The piles have been attacked by sea-organisms from about 13 feet above L.W.O.S.T., but considerably more so from a height of about 6 feet above L.W.O.S.T. to the ground line, which averages 9 feet L.W.O.S.T., i.e., the piles have been attacked for a range of about 22 feet. It is stated that the pitch pine piles came from Pensacola and Mobile. The pitch pine cross-bracing up to the same level has been similarly attacked.

The structure is tarred each year down to about 3 feet above L.W.O.S.T., but this has not been effective against the attack of the sea-organisms.

The length of pier, marked D. on the Plan, was constructed in 1881/2, with pitch pine piles and bracings and has been affected by sea-organisms in the same way as the adjoining length C.

The original pier, marked E. on the Plan, was constructed in 1840, and consists of cast-iron plates tied back with 1½ inch wrought-iron rods attached to anchor piles of Baltic timber. These cast-iron plates are 1 inch in thickness, and where exposed are coated with gas tar annually and no corrosion of the metal open to inspection has taken place.

About 1850 this length of pier was widened for the purpose of forming a lower platform for landing at low water, by constructing a pitch pine timber pier in front of the cast-iron pier. In order to preserve the timber piles in this structure, some of them were copper sheathed for a short length, with felt intervening, and the copper was fastened with copper nails to the piles. Another method adopted in this length consisted of applying an iron casing, about 5 feet in length, formed in separate halves, bolted together round the piles. Both these methods proved effective against the attack of the sea-organisms for the length so covered, but immediately above and clear of the casing, in each case, the piles were attacked similarly to those in the length C.

The length marked F. on the Plan indicates the extent of the new, or widened, pier constructed in 1912/13 to enable passenger trains to arrive at and depart from a new riverside passenger platform.

In 1907 the old timber pier was widened and extended for the length marked G. on the Plan. This structure consists of Tasmanian blue gum piles, from 60 to 70 feet in length, and 15 inches square, with karri, jarrah, and pitch pine bracings, and to a small extent Oregon pine. This last has been much affected by the sea-organisms, and the karri and jarrah slightly so, while the blue gum suffers very little, if at all.

Careful records of these Tasmanian blue gum piles will be kept and reported on further from time to time.

These structures B. to G. inclusive are subject to the action of fresh water from the river Wyre, as also to sea-water.

Jetties at Lancashire and Yorkshire Company's Dock Entrance.—These

FLEETWOOD.

Pile of Pitch Pine at Fleetwood showing portion damaged by sea action.

Jetties, marked H. on the Plan, constructed in 1877, on the east side, and in 1883 on the west side, of the entrance of the dock, consist of pitch pine timber piles and bracings throughout and have been attacked by sea-organisms in the same way and extent as the pitch pine timbers in the harbour berths and are subject to the same tidal range.

Lancashire and Yorkshire Company's Wyre Dock.—The lock-gates, marked J. on the Plan, are of wrought-iron and, where possible, they are thoroughly cleaned and coated (two coats) with gas tar every year, and this has been found effective in preserving the wrought-iron from the action of the sea-water.

At the point marked K. on the Plan, a timber casing and fenders of pitch pine, covering certain pipes, were fixed in 1882, and when renewed a short time ago it was found that the timbers, originally 11 inches square, had been reduced by the action of the sea-organisms to 6 inches square; the action in this case being more rapid than in the harbour.

The photograph, see Plate III., annexed hereto, is that of one of the piles, removed about 5 years ago, from the length of the pier erected in 1882, and marked D. on the Plan; it may be taken as a very fair illustration of the results of the attack of the sea-organisms on the pitch pine timber structures in the Fleetwood Harbour.

This pile had formed one of the outer row of piles in the structure for a period of 30 years and it will be seen has been attacked from the ground level 9 feet below to 13 feet above zero or L.W.O.S.T., but mainly below zero where the pile originally 14 inches has been reduced to 8½ inches square.

The small crustacean, called *Limnoria lignorum*, appears to attack and works its way into the softer parts of the timber, and the borings are so close together that the timber, immediately below the surface, becomes so honeycombed and disintegrated as to permit of the water washing away the surface and by constant repetitions of this process the pile or timber is gradually reduced in thickness.

It would appear from the observations taken at Fleetwood that the softer woods such as Oregon pine and spruce are much more readily attacked than even pitch pine, that karri and jarrah timber are also subject to the action of the limnoria, but as regards the Tasmanian blue gum a further period of observation is necessary to determine definitely the results of such action.

Reinforced Concrete Staging and Piling for New Fish Dock.—The main portion of the above, marked L on Plan, consisting of quays for unloading fish, for coaling steam trawlers, with quay lengths of 1,330 feet and 680 feet respectively, was constructed between May 1909 and June 1911.

The construction, which is on the Hennebique System, and may be considered as practically the same throughout, is composed of reinforced concrete trestles, spaced 10 feet apart from centre to centre, supporting a reinforced concrete deck.

The front row of piles are 12 inches × 12 inches in section, 37 feet long. They are reinforced with four bars of round mild steel, 1⅛ inch in diameter, spaced so as to have a minimum depth of concrete between the bars and the outside of the pile of 1½ inch. The bars are held

together by 54 sets of $\frac{3}{16}$ inch steel wire links and are kept apart by 9 sets of cast-iron cross struts.

The middle and back rows of piles are 22 feet long, 12 inches × 12 inches in section, and of a similar construction to the above. These rows of piles are connected transversely by 12 inches × 12 inches, and 12 inches × 8 inches reinforced concrete bracings and longitudinally by reinforced concrete sheet piling in front and a 12 inch × 12 inch reinforced concrete beam in the centre.

The decking is constructed of reinforced concrete beams and slabs made monolithic with the trestles. The lower portion of the deck is of reinforced concrete $2\frac{1}{2}$ inches thick between the beams, above which is a thickness of $1\frac{1}{4}$ inch of granolithic finish of $3\frac{1}{2}$ to 1 concrete.

To form a retaining wall at the front of the quay, the sheet piles are driven in line with and between the front row of king piles. These are 18 inches × 9 inches in section and 28 feet long. They are reinforced with four round bars $1\frac{1}{4}$ inch in diameter, of mild steel, at the corners, spaced so as to have a minimum depth of $1\frac{1}{2}$ inch between the bars and the outside of the pile. The bars are held together with 53 sets of $\frac{3}{16}$ inch steel wire links, and are kept apart with 7 sets of cast-iron struts.

The sheet and king piles are connected with each other by a longitudinal 12 inch × 12 inch ferro-concrete headpiece moulded into the king pile extensions, so that the monolithic nature of the whole structure is maintained.

The piles were constructed in timber moulds laid horizontally on the ground, and were driven in position by Lacour steam pile-engines with 2-ton rams.

The works are examined periodically, and up to the 1st February, 1917 (about 8 years after the commencement and 6 years after the completion of the works) no defects were discovered above high-water mark.

The deck, both on the surface and on the underside, the deck beams, and the pile extensions, above high-water mark, were in perfectly good condition.

In 1915 rust marks were first noticed on the face of the reinforced concrete, mostly circular, of about 1 or 2 inches in diameter, caused for the most part by small holes, often less than $\frac{1}{16}$ inch in diameter, between the face of the concrete and the steel links and bars, by means of which the water attacked the steel. These marks were entirely confined to the reinforced concrete constructed *in situ*, no defects being apparent on the sheet piling exposed to the same conditions.

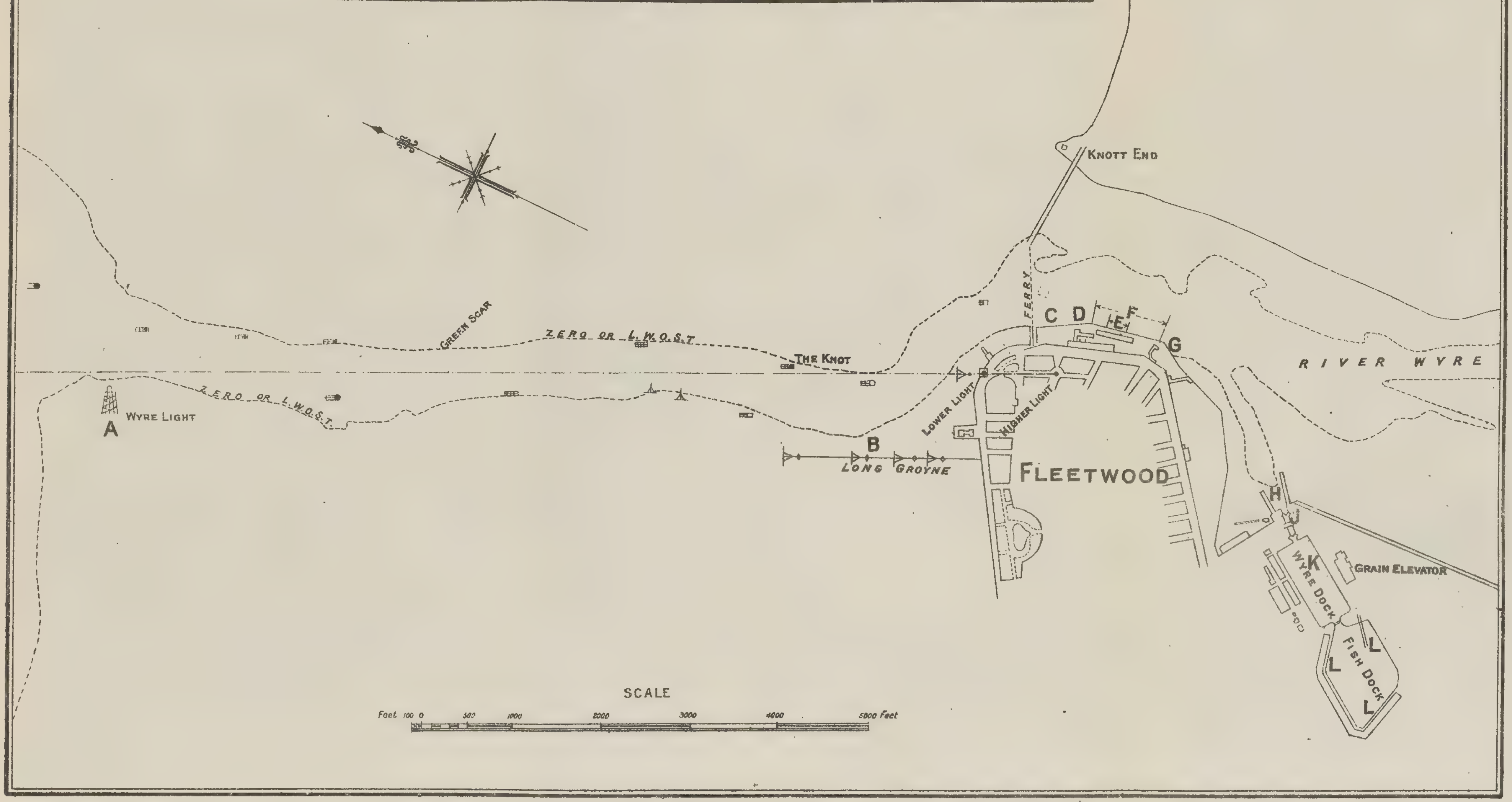
The major portion of the structure shows a negligible proportion of these latter defects, which are local and point to the fact that they occur in such portions of the concrete as were moulded under the worst tidal and weather conditions.

The members where most defects occur are the 12 inches × 8 inches diagonal struts between the front and middle row of piles. Some of the larger rust marks, on being scraped or dressed off, show the concrete clean underneath and are ultimately traceable to a very small hole—such as already described—which penetrates to the reinforcement.

A few of the junctions of members are affected, as described above,

FIG. 3.

L. & Y. AND L. & N. W. JOINT RAILWAYS & HARBOUR
AND
L. & Y. RAILWAY Co^{s}. DOCKS AT FLEETWOOD.



more particularly those at the lower side of the front diagonal strut to trestles, and in cases where these defects have been probed the reinforcement has been found to be less than the prescribed $1\frac{1}{2}$ inch back from the surface of the concrete. As far as can be seen, none of the piles have suffered injury through driving, nor is there any evidence of damage by the bumping of ships. The concrete throughout the reinforced structure shows no sign of deterioration.

Protection by Waterproof Coating.—In order to remedy these defects it was decided to coat the whole of the reinforced concrete structures, from and including the underside of deck and deck beams downwards as far as the water would permit, with one coat of tar and naphtha, in proportions of eight parts of tar to one of naphtha. This mixture formed a good skin which dried in about $1\frac{1}{2}$ hour where the concrete was dry. Particular care was taken to fill up the pores as far as possible. This work is now in progress and the results will be reported from time to time.

GLASGOW AND CLYDE NAVIGATION.

By W. M. ALSTON, M.Inst.C.E., Engineer to the Clyde Navigation Trustees.

Within the limits of the Clyde Navigation there are no piers of cast iron or wrought iron, and the only ferro-concrete work which the Navigation Trustees have constructed is a piece of wharfing about 180 feet long by 30 feet wide, now about 9 years old. The underside of the decking of this structure has begun to scale slightly, due probably to want of care in joining the various progressive sections of the work.

At a recent fire, caused by oil on the surface of the water becoming ignited by hot rivets or by hot ashes thrown into the water, the flames passed along the face of this wharf leaving it practically unhurt, and set fire to an adjoining wharf 300 feet in length, constructed of creosoted timber, doing much damage.

I have no experience of tar being applied to the surface of ferro-concrete work to prevent water from gaining access to the interior steel work.

With regard to timber, it has been found that impregnating it with 8 lbs. of creosote oil per cubic foot is an excellent preservative, and piles driven about 58 years ago are still in good condition. Owing to this satisfactory experience, all timber used for wharfing has been creosoted; but in view of several bad fires which have occurred quite recently from the ignition of oil in the water area of the harbour it looks as if it will not be safe in future to expose creosoted timber to this risk, and that ferro-concrete piles will have to be substituted.

The only cast-iron work used under water in structures belonging to the Clyde Trustees is to be found in sluices, and such like, and this material is looked upon as being practically indestructible. As regards wrought-iron work, I can only refer to the caissons at the entrance to the Trustees' three graving docks, the first of which was built in 1875, the second in 1886, and the third in 1898. In every case the structures are in excellent order. I may mention that a thick coating is formed upon

the surface of all iron work by impurities in the water, and this seems to act as a preservative.

As to the salinity of the water in Glasgow Harbour, it is very much diluted. Mr. F. W. Harris, F.I.C., the Glasgow Corporation Chemist and City Analyst, informed me that he had found that a sample, taken on a falling tide at Queen's Dock, Glasgow, contained 60·6 grains of salt per cubic foot ; a sample taken at high water at Bowling Harbour, about 11 miles below Glasgow, contained 966·3 grains ; and a sample taken 2 hours after high water opposite Custom House Quay, Greenock, 21 miles below Glasgow, contained 12,692 grains per cubic foot. As having a bearing on the salinity of the water, I may state that seaweed is not found higher up the river than about 11 miles below Glasgow. There are no sea-organisms in the water of Glasgow Harbour.

I send a plan of the river showing Glasgow Harbour and Docks and the limits of the Clyde Trustees' jurisdiction.

GRIMSBY AND IMMINGHAM DOCKS.

By G. CARTWRIGHT, M.Inst.C.E., Docks Engineer.

GRIMSBY DOCKS.

The Port of Grimsby is situated on the south shore of the estuary of the Humber, about seven miles west of Spurn Point. The dock entrances are protected by four piers, *viz.*, the east and west piers of the Royal Dock and the old and new piers of the Fish Dock. High water of ordinary Spring tides is 11·00 feet above Ordnance Datum.

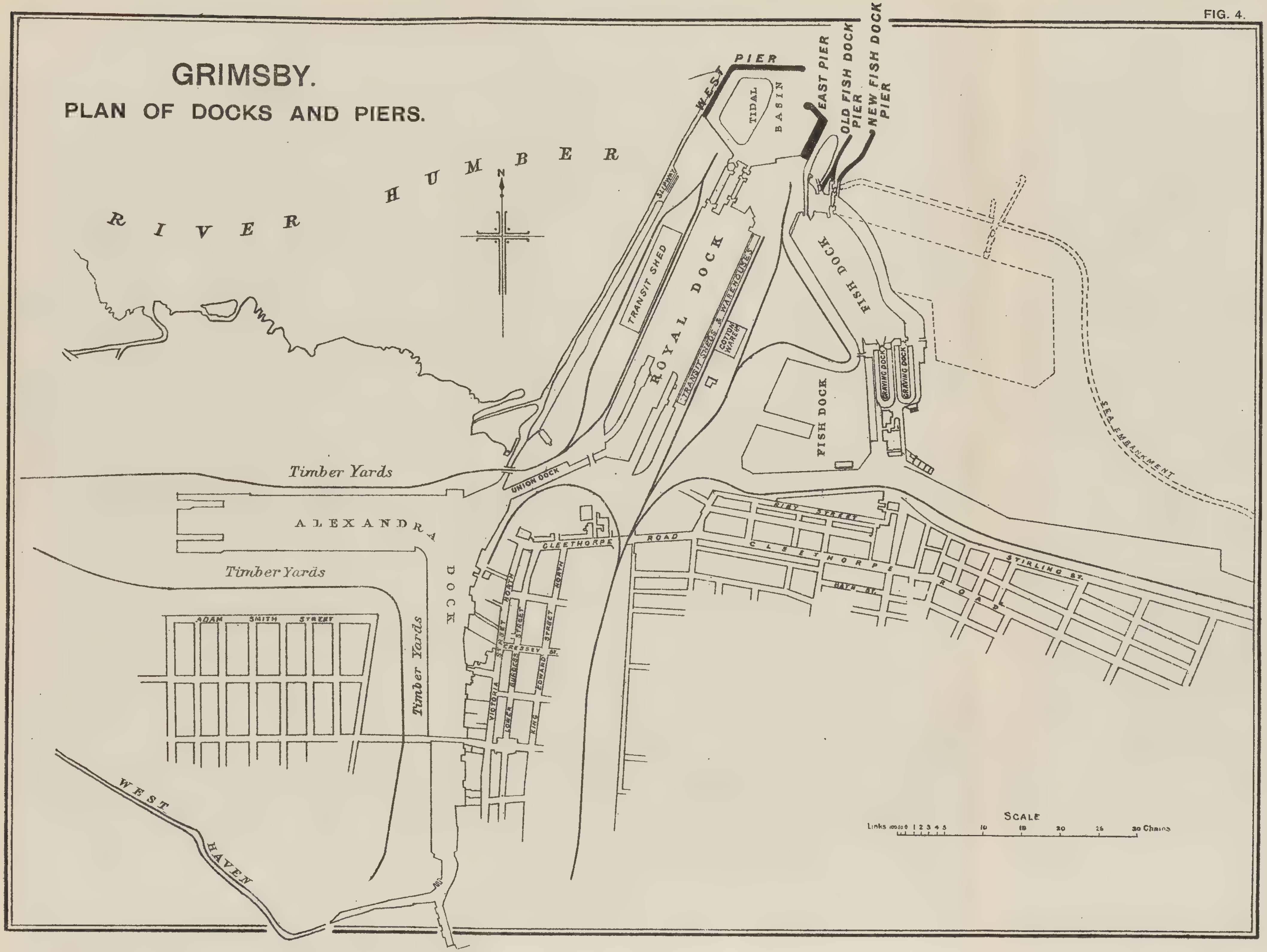
Spring tides rise	19·50 feet.
Neap tides rise	15·50 feet.
Neap range	10·50 feet.

The water in the Humber at Grimsby may be taken as consisting of about 80 per cent. of sea-water and 20 per cent. of fresh water. There are no appreciable chemical discharges and the sewage discharge forms too small a proportion of the total volume of water to have any effect on the sea-organisms accountable for the destruction of timber.

The *Teredo navalis* is not found in the Humber Estuary, and there are no signs of its presence at Grimsby, but the *Limnoria lignorum* abounds.

The east and west piers enclose a tidal basin, which forms the approach to the Royal Dock. They are open-timber, piled structures, and were originally constructed of creosoted Memel red fir in 1851–1855. The east pier is 800 feet long, 21 feet wide at deck level and 9 feet above H.W.O.S.T. The west pier is 1,330 feet long, 24 feet wide at deck level and 9 feet above H.W.O.S.T. Of the original timber in these structures only a few piles remain. Above high-water level these are fairly sound and well preserved, exhibiting little of the softness usually found in timber that has been exposed to the weather for such a long time. This is probably due to the drying effects of the winds to which the piers are exposed. Between high and low water level the timber has been destroyed

FIG. 4.



GRIMSBY.
PLAN OF DOCKS AND PIERS.
RIVER HUMBER
N
WEST PIER
TIDAL BASIN
EAST PIER
OLD FISH DOCK PIER
NEW FISH DOCK PIER
TRANSIT SHED
ROYAL DOCK
TRANSIT SHEDS & WAREHOUSES
COTTON WAREH.
FISH DOCK
FISH DOCK
GRAVING DOCK
GRAVING DOCK
SEA EMBANKMENT
Timber Yards
UNION DOCK
ALEXANDRA DOCK
Timber Yards
Timber Yards
CLEETHORPE ROAD
RIBY STREET
STIRLING ST.
BATH ST.
ADAM SMITH STREET
NORTH
NORTH STREET
VICTORIA STREET
CRESSEY ST.
BURGESS
EDWARD
LOWER
KING
WEST HAVEN
SCALE
Links 100 50 0 1 2 3 4 5 10 15 20 25 30 Chains

by the limnoria. Below low water level the piles are embedded in silt and are in good condition.

In 1885–1886 the east pier was renewed and the whole of the original work, except a few piles, was removed, the reconstruction being carried out in creosoted Memel red fir. Above high-water level the timber is souud and good. Between high and low water it has been eaten away by limnoria to a depth of $1\frac{1}{2}$ inches from the original surface. Below low water the timber is embedded in silt and is quite sound.

The west pier was reconstructed of creosoted Memel and Dantzig red fir in 1896–1901. Between high and low water it has been attacked by limnoria and eaten to a depth of $\frac{1}{4}$ inch into the timber. Above high water and in the silt below low water the timber is unaffected. A noticeable feature in this pier is that the exposed ends of the foot blocks supporting the struts at the level of L.W.N.T. have been eaten away for a length of about 4 inches.

The old Fish Dock pier is a light construction of open-timber pile work of creosoted Memel. Above high-water level the timber is still fairly sound, and no appreciable reduction of scantling has taken place. Between high and low water the structure has been badly attacked and nearly all the piles have been practically destroyed by limnoria.

The pier was lengthened in 1873, the timber used being creosoted Memel. Between high and low water level the piles have been eaten into to a depth of $1\frac{1}{2}$ to 2 inches from the original surface. Elsewhere the timber is sound throughout.

The new Fish Dock pier is 630 feet long, 20 feet wide at deck level and 7 feet above H.W.O.S.T. It is of open pile work and is constructed of creosoted Dantzig red fir with the exception of the sheet piling, which is untreated pitch pine. It was completed in 1906. All the Dantzig timber is quite sound and good, but the pitch pine sheeting, the whole of which is below H.W.O.S.T., has been attacked by limnoria and eaten away to a depth of about an inch. The plan of Grimsby which shows the position of the structures mentioned is appended. (See Fig. 4.)

IMMINGHAM DOCK.

Immingham Dock is on the south side of the Humber, six miles above Grimsby and ten miles below Hull. The dock entrance is protected by two jetties of open timber pile work, constructed in 1908–1912. The piles are of jarrah and the bracing and other timber work between high and low water are of creosoted Memel. The jarrah is unaffected, but the Memel is beginning to show signs of the attack of limnoria at low-water level.

HARTLEPOOL HARBOUR.

By J. D. HOWKINS, M.A., M.Inst.C.E., Engineer of the Port and Harbour Commission.

The breakwater, which is the most important structural work in the custody of this Board, has a total length of 440 yards, of which half is built of stone and the outer half of concrete blocks. The first portion

was commenced about the year 1853 and the latter in 1869, and it was finished to its present length in 1890. The first part calls for little comment, as the stones exhibit no deterioration other than a slight weathering of the parapet and part exposed to heat and frost. No boring shell fish have attacked the lower courses of the work. Most of the hearting was of rubble, but a certain number of blocks made of limestone and lime concrete were included. With regard to the outer or concrete part of the breakwater no deterioration of any consequence in the concrete has taken place. With reference to another work of the Hartlepool Port and Harbour Commission, namely, the Old Pier, there was here a failure caused by chemical impurities described in a Paper contributed by me to the Institution in 1911.[1]

Any other cases of deterioration which have taken place have not been caused by sea-action but by unequal expansion and contraction, and these have been confined to comparatively thin surfaces.

Reinforced concrete has also been used in the place of timber with satisfactory results.

HEYSHAM HARBOUR, MORECAMBE BAY.

By BALDWIN BENT.

Heysham is an open tidal harbour with an area of 36 acres, and an entrance between two roundheads 300 feet apart. The main feature of the site is the channel called Heysham Lake, with a natural depth of 40 feet at low-water, within 500 yards of the roundheads, on gaining which channel a vessel leaving the harbour can then proceed full speed ahead.

The nearest volume of fresh water is the River Lune. The direction and distance of its mouth from the entrance to Heysham varies considerably at different states of the tide. At high water its direction is S. by E., and its distance away about $3\frac{3}{4}$ miles; whilst at low water its direction is S.W. $\frac{1}{2}$ W., and the distance to it is $4\frac{3}{4}$ miles.

The rise of ordinary spring tides is 27 feet and of neaps 21 feet.

The construction of the harbour was begun in 1897, and it was carried out in the dry. Water was let in during September, 1903, and the harbour was opened for traffic in 1904. The structures have, therefore, only been submerged some 14 years, and the deterioration is comparatively slight. An account of the harbour by Mr. G. N. Abernethy has been printed in the Proceedings of the Institution.[2]

The walls are composed of 7 to 1 mass concrete, with a face 9 inches thick of 5 to 1 concrete. They are founded on rock or boulder clay; where this could not be reached in open trenches monoliths were sunk to carry the walls and roundheads, the one carrying the south roundhead is 55 feet in diameter, and it was sunk 72 feet on to rock. The concrete shows no signs of deterioration, so no further allusion will be made to it.

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[1] Minutes of Proceedings Inst.C.E., Vol. clxxxviii, p. 413.
[2] *Ibid.*, Vol. clxvi, p. 229.

The timberwork consists mainly of the following :—

(*a*) Timber landing stages, 1,760 feet long on the south side of the harbour, constructed of karri and creosoted pitch pine. The lowest part of the timber is 10 feet above harbour bottom and 7 feet below L.W.O.S.T. Five samples of timber have been taken from this section. They are labelled A i, A ii, A iii, A iv, and A v, to correspond with the same letters on the drawing indicating the positions from which the respective samples were cut. (See Fig. 6.)

(*b*) Continuing westward along the South Quay, just before reaching the proposed lock entrance, there is a recess in the wall carrying an electric cable to an earth-plate, which recess is covered with a tarred pitch pine board. Two samples have been cut from this board, labelled B i and B ii respectively, the same lettering being given on the drawing showing the levels they came from.

These samples are sent as the board from which they were cut is the only bit of timber about this part of the harbour, and the position is one where, in addition to destruction caused by the worm and by the ordinary tidal currents, there is a certain amount of wash from every vessel entering or leaving the harbour, no matter what berth she may be going to or leaving. The samples are specially sent, since it may be concluded that the greatest amount of deterioration in any timber will take place in such a position as this, where the work done by the worms is helped by currents and the greatest amount of wash.

It will be remembered, when comparimg these samples with the pitch pine from the Section A, that the former were not creosoted, only tarred, and that the latter have only been submerged 9 years, as against 14 in the case of samples A.

(*c*) A heavy timber jetty, 1,000 feet long, on the south side of the dredged entrance channel from Heysham Lake to the harbour. It is made of karri piles, with cross timber walings, &c., of creosoted pitch pine, with blue gum rubbing pieces on the piles.

The site of the jetty is shown on the General Plan, Fig. 5, and a section marked C. is given on Fig. 6. Two samples of timber have been taken from this section; they are labelled C i and C ii, and their respective positions are shown on the drawing.

As Heysham Harbour has been in existence for so short a period this report can be but of little interest. A far better place in this neighbourhood from which to collect information would be Fleetwood, where, owing to the action of the marine worm over a longer period of time, a considerable amount of timberwork has had to be renewed.

In conclusion, it is suggested that decisions should not be formed too hastily. For instance, supposing a structure to be made of two classes of timber, the softer of which shows signs of being attacked by worm whilst the other appears to be immune, it does not follow that there would have been any great gain if only the harder wood had been used in the first instance. A case in point which occurred in South Africa may be quoted. It was decided when repairs became necessary, through the destruction of the softer of two timbers, to replace this material entirely with the wood which showed no deterioration. The result was that the worm, having

to live and not having the softer timber which it preferred, was driven perforce to attack the other; this it did with apparently no trouble at all.

Note.—With regard to the creosoted pitch pine there was no particular specification for this. It had to be done "to the satisfaction of the engineers," and it was well done, the timber having evidently absorbed all that was possible.

All the timber, karri and pitch pine, was coated before erection with a mixture of coal tar, naptha, and salt, laid on hot, a second coat being given after the structure was up.

HOLYHEAD HARBOUR.

By E. F. C. TRENCH, M.A., M.A.I., M.Inst.C.E., Member of the Special Committee.

The Port of Holyhead, although not one of first importance, is practically on the open sea, the water in the harbour not being diluted to any great extent by fresh water, nor contaminated with sewage or trade effluent. The experience gained by an examination of the structures there may therefore, prove of value in dealing with ports where similar conditions exist.

The range of spring tides is about 17 feet 6 inches and of the neaps 8 feet 8 inches. The harbour is well sheltered so that the structures are not exposed to heavy wave action. The quays are constructed of masonry built of limestone and of other stone obtained in the locality, and there are piers constructed of greenheart, pitch pine, and Memel; also of cast-iron with wrought-iron bracings, some of these being protected by concrete in bags. Some of the pitch pine and Baltic piles have been creosoted, others have not.

Timber.—The teredo is not found, but all the wood is attacked by limnoria, and these, when once established, make rapid progress in the demolition of timber, no variety of which effectively withstands their ravages. After a time these crustaceans multiply in such numbers that their galleries or burrows cross one another so as to form an intricate honeycombing of the timber, and as they progress and eat deeper the outer surface of the timber is broken away by wave action. The attacks are not confined to sapwood only, and greenheart is destroyed and eaten away, although at a slower rate than softer timber.

A study of the piles shows that it is very difficult to generalise as to the best method of preservation, but it seems probable that creosoted timber resists attack for some time. A number of piles have been very carefully examined, and the following are some typical instances of their condition at the present time:—

The original dimensions of the piles in each case were 14 inches by 14 inches.

Greenheart.—Two piles, 12 feet apart, both fixed 20 years. One is eaten to a depth of 2 inches all round, and the other shows only slight traces of attack.

Clean pitch pine.—Two piles, 12 feet apart, both fixed 20 years. One eaten completely away and the other to about 9 inches by 9 inches.

FIG. 5.

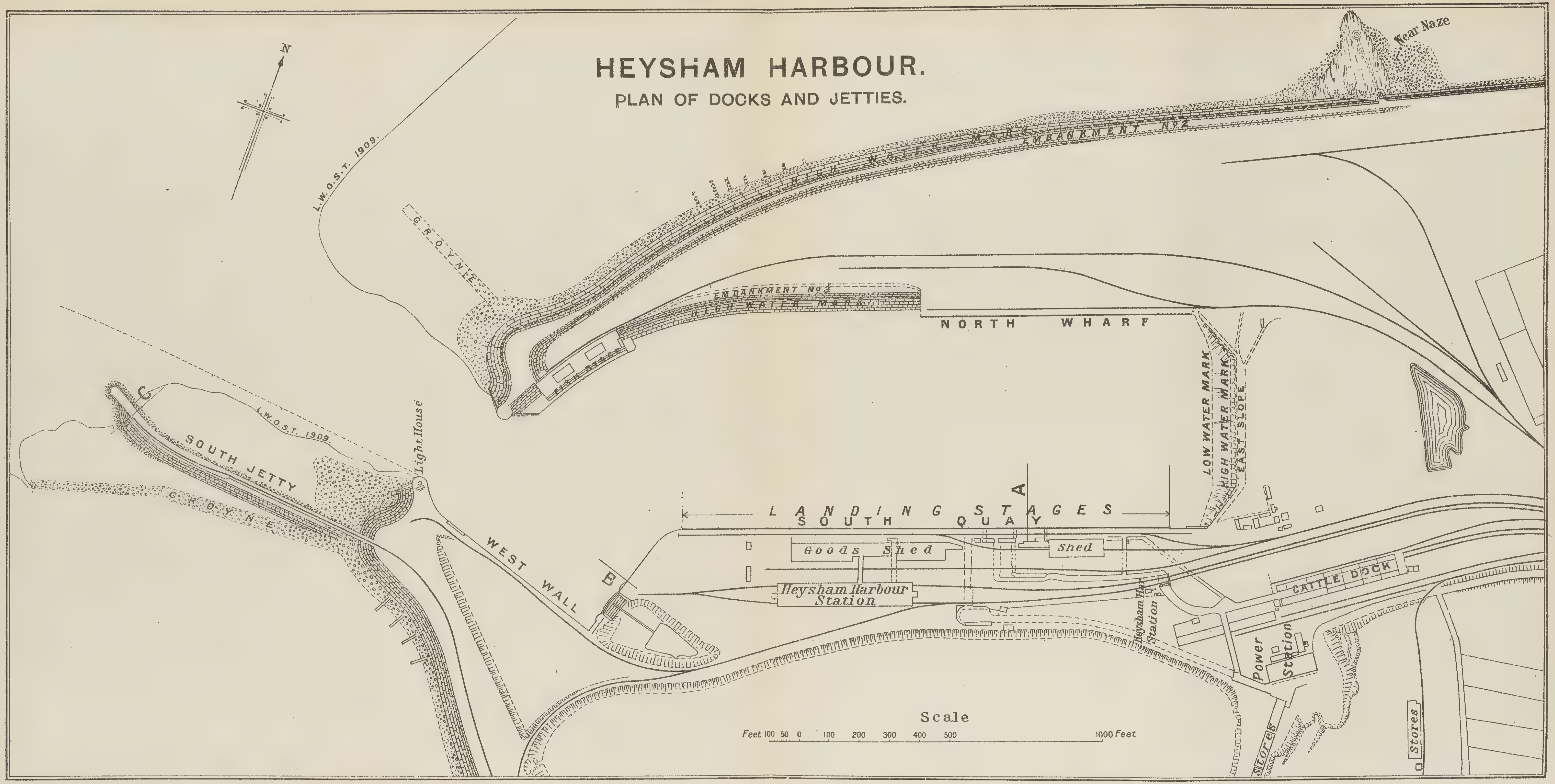
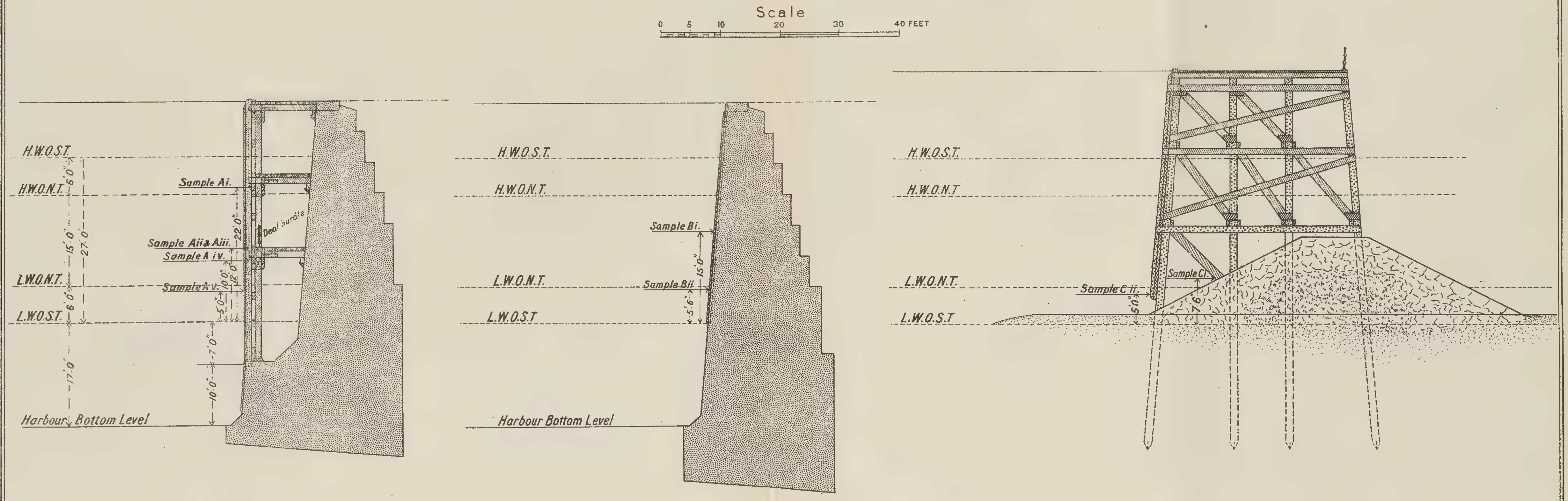

HEYSHAM HARBOUR.
PLAN OF DOCKS AND JETTIES.
N
Near Naze
EMBANKMENT No 2
HIGH WATER MARK
L.W.O.S.T. 1909.
GROYNE
EMBANKMENT No 3
HIGH WATER MARK
FISH STAGE
NORTH WHARF
LOW WATER MARK
HIGH WATER MARK
EAST SLOPE
C
L.W.O.S.T. 1909
SOUTH JETTY
GROYNE
Light House
WEST WALL
B
A
LANDING STAGES
SOUTH QUAY
Goods Shed
Shed
Heysham Harbour Station
Heysham Har Station
CATTLE DOCK
Power Station
Stores
Stores
Scale
Feet 100 50 0 100 200 300 400 500 1000 Feet

FIG. 6.

HEYSHAM HARBOUR.

Details of Concrete Work and Timber Jetties.



Section A – Landing Stages at South Quay.

Section B – Wall Proposed Lock Entrance.

Section C – Timber Jetty

Creosoted pitch pine.—Two piles, 40 feet apart. One fixed 9 years, eaten to about 9 inches diameter; and the other, fixed 10 years, shows no sign of attack.

Creosoted Baltic.—Two piles, 110 feet apart. Age of one not ascertained, but known to be over 23 years; this is attacked in a few small patches; and the other, fixed 18 years, is irregularly eaten into pot-holes 3 inches to 4 inches deep.

During the last ten years many of the piles have had the bottom half renewed by scarfing various kinds of timber to the upper portions. Of these clean pitch pine was found showing traces of attack after 3 years and to 1 inch deep all round after 5 years. Creosoted pitch pine, traces showing at ages varying from 5 to 10 years. Clean Baltic 1 inch deep all round after 7 years, and eucalyptus 1 inch deep all round after 7 to 10 years.

The foregoing instances are sufficient to show how contradictory is the evidence to be gained from a superficial examination. Excluding preservative treatment for the present, it would seem there is evidence to prove that some of the timbers in each variety have power to retard attack; possibly this may be due to the better quality of the timber, and to whether the log was fixed the natural way or butt end up, the latter having occurred in some cases. The ability to retard attack may depend on the climatic conditions under which the timber was grown, whether the growth was slow or rapid, the nature of soil, the age and size of the standing timber from which the log was cut, and the percentage of sapwood. There is little doubt that many of the logs varied considerably as regards the amount of sapwood, some of the greenheart taken out of the harbour works showing about 30 per cent. of sapwood.

It would appear that the demolition of the respective logs is in direct ratio to the percentage of sapwood in the logs when they were first fixed, and had the greenheart been free from sapwood it would probably have taken many years for the limnoria to become established.

With regard to the timber subjected to preservative treatment, no evidence exists of its condition as regards seasoning and moisture. The presence of moisture must militate against the proper impregnation of the timber with preservative, and this may possibly partly account for the fact that some of the creosoted piles resisted attack for a longer period than others. Creosoting certainly does for a time act as a deterrent, but Baltic and pitch pine so treated are attacked eventually, and when once attacked the destruction of the timber proceeds rapidly. Creosoted Baltic seems to be quite as good, and possibly better than creosoted pitch pine, although the latter when not creosoted is more satisfactory than Baltic timber not creosoted.

Ironwork.—All the wrought-iron bars and bracing in the Fish Jetty, constructed in 1878, and the cast-iron columns above low-water level are periodically cleaned and tarred, and they appear to be in a good state of preservation. Below low-water level the columns are not so treated, and they, as well as the cast-iron shutter plates, are heavily encrusted; in many places the encrustation on the cast-iron shutter plates is more than 1 inch thick. The action of the sea-water has caused the metal to perish to a

depth of more than $\frac{1}{4}$ of an inch, and the perished portion is similar to plumbago, and can be easily cut with a knife. The old rail piles are all badly encrusted and are perishing, while the hook bars are in many cases entirely rusted away. The wrought-iron straps, securing fender piles, are generally fairly good, but some are badly pitted.

Masonry and Concrete.—The quay walls, which were built about fifty years ago, are all in excellent preservation. They are thickly covered with marine growth up to neap tide level, except in certain places, where the walls are covered with a film of grease. Some of the limestone is penetrated by a mollusc to a depth of about 2 inches, but these bore holes are not sufficiently numerous to affect the solidity of the structure.

The concrete in bags is in very good condition, and a sample of concrete, which has been in position for 35 years, still shows the sacking adhering to it, while in other cases the seam and texture marks of the bags are still quite definite. The concrete as a whole does not show any signs of deterioration.

THE PORT OF LEITH.

By ALFRED H. ROBERTS, O.B.E., M.Inst.C.E.

A PIER at this port is constructed of pitch pine timber with a solid hearting of squared masonry, the timber work constitutes a facing on the harbour side. The portion of the pier in question was constructed about 1848. Through the harbour there flows the fresh water of the small river known as the Water of Leith. This stream normally discharges a very small volume of water, though with heavy rains on the Pentland Hills strong freshets come down. The top of the solid stone hearting is about 2 feet above H.W.O.S.T. (See Fig. 8.)

Many years ago a large amouut of sewage was discharged into the Water of Leith, until matters became so insanitary that a Parliamentary Commission, known as the Water of Leith Purification Commissioners, was created for the purpose of purifying the stream. They began operations about the year 1893, and by the construction of special sewers and by works of purification they have now rendered the river practically a clean stream.

It is not possible to say with certainty whether the presence of sewage in the water in earlier time had the effect of restraining the ravages of the worm, but there seems to be no doubt that the rate of deterioration by worm has considerably increased in recent years.

Two samples accompany the report, the first taken from the diagonal bracing, 12 inches by 6 inches, at the outer end of the pier at about half-tide level, see Plate IV., and the second is taken from the entrance jetty to the Imperial Lock Basin, which was constructed about the year 1900. This latter specimen indicates a very much more rapid rate of destruction than in the case of sample No. 1. There is no evidence of the presence of teredo, and I think all the destruction is wrought by limnoria.

Reinforced concrete has only been employed at the Port of Leith in recent years beginning in 1913 and has been used for the construction

PORT OF LEITH.

Entrance Je[illegible]

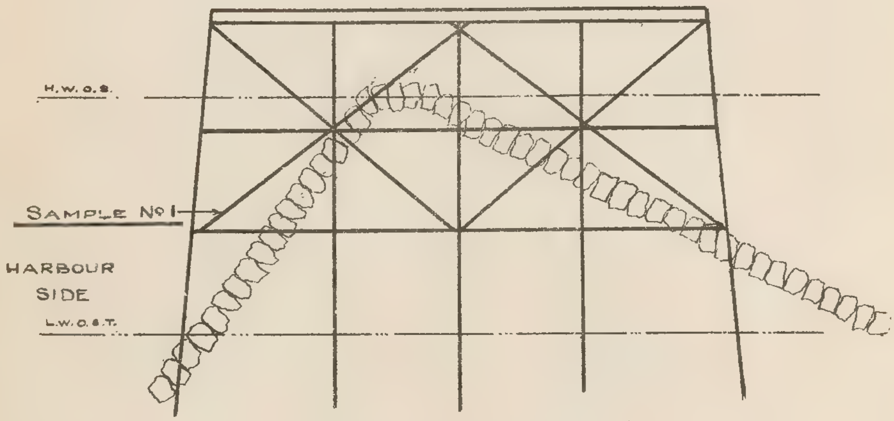
FIG. 7.


PLAN
OF THE
HARBOUR AND DOCKS
OF
LEITH
SCALE
100 0 100 200 300 400 500 1000 FEET
SAMPLE No. 1
SAMPLE No. 2
SAMPLE No. 3
WEST PIER
OUTER HARBOUR
IMPERIAL DOCK JETTY
Basin
IMPERIAL DRY DOCK
Lock
IMPERIAL DOCK
SHED
SHED
SHED
SHED
Albert Dock Basin
Lock
ALBERT DOCK
EDINBURGH DOCK
PRINCE OF WALES DRY DOCK
DRY DOCK
Shipbuilding Yard
Shipbuilding Yard
SHED
SHEDS
VICTORIA DOCK
SHED
SHEDS
DRY DOCK
DRY DOCK
WEST OLD DOCK
EAST OLD DOCK
WAREHOUSES
WAREHOUSES
COMMERCIAL STREET
STATION
DOCK ST.
CUSTOM HOUSE
INNER HARBOUR
TOWER PLACE
TOWER STREET
CONSTITUTION PL.
CONSTITUTION ST.
ALBERT ROAD
BATH ROAD

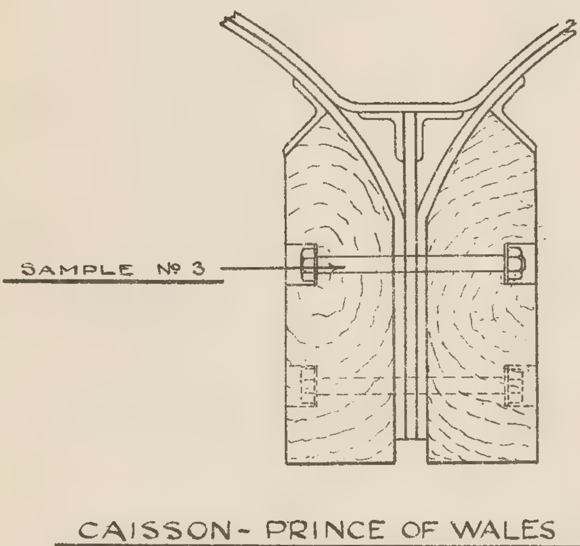
FIG. 8.

PORT OF LEITH

Details of Pier and Caisson.



WEST PIER



CAISSON - PRINCE OF WALES DRY DOCK

or reconstruction of quay-walls. There is no indication of any deterioration of this concrete.

In cases where reinforced concrete structures exist between high and low water mark, the custom is to coat the surface with tar, as an additional safeguard against the possibility of water finding its way in to the reinforcement.

Ordinary concrete was used in the form of blocks for the construction of breakwaters or reclamation walls (see plan) about the years 1875/1880 and again in 1895/1900. The whole of this concrete is sound, and gives no indication of any deterioration from the action of sea-water. The aggregate consists of freestone from the well-known Craigleith Quarry, from which most of the stone employed for facing the dock walls and otherwise was also obtained; the sand was brought from the foreshore at Musselburgh.

In 1909/1911 mass concrete with concrete facing was employed in the construction of the Imperial Dry Dock, and here also the surface shows no signs of deterioration. In this case the aggregate is composed of machine-crushed whinstone obtained from North Queensferry, ranging in size from $1\frac{1}{2}$ inch to about $\frac{1}{8}$ inch, with the dust screened out. Fairly coarse sharp sea-sand from certain parts of the beach at Kirkcaldy in Fife was used, and the proportion of aggregate to cement was generally 6 to 1, with 4 to 1 in facework. The cement in this case was manufactured by the rotary process.

There are in this port a number of pairs of dock gates and a ship's caisson, but, generally speaking, these are all in good condition.

The caisson of the Prince of Wales Dry Dock, which opens directly into the harbour (see plan), was constructed in the year 1861. It was recently dry-docked for examination and overhaul. The plating has become considerably pitted, the depth varying to $\frac{1}{8}$ inch maximum.

In case it may be of interest to the Committee, a bolt is herewith forwarded, together with a sketch, see Fig. 8, showing its position in the keel of the caisson. The corrosion apparent at either end is undoubtedly caused by the oak timber which was used for clapping pieces, the centre portion of the bolt having been embedded in the iron keel. Probably the whole of the corrosion is explained by the acid in the oak, but it may have been aggravated by the presence of salt water.

Iron and steel dock gates have been constructed at intervals from 1868 to 1911. These have all been kept constantly painted, and there is no evidence of appreciable deterioration. A general plan of the harbour and docks is appended, Fig. 7.

LIVERPOOL AND BIRKENHEAD.

By THOMAS M. NEWELL, M.Inst.C.E., Engineer-in-Chief, Mersey Docks and Harbour Board.

In the first place it is to be noted that in this locality there are but few existing examples of structures which would be subject to serious deterioration from the causes named, and for this there are two main reasons.

First. The range of tide is very considerable, varying from 10 feet on lowest neap tides to 34 feet on highest equinoctial spring tides, and consequently piled wharves—a very usual mode of providing berthage for vessels in the early development of ports—while costly by reason of their height if the vessels had to be kept afloat, were also but indifferently suitable for discharging and receiving goods, on account of the great vertical range of movement of the vessel during the tide, even if we assume that by giving suitable protection vessels could lie alongside in safety in all winds. From an early time in the history of the Port of Liverpool, the main accommodation for shipping has been provided in the form of enclosed docks, in which the water is impounded at high-water level. There are no really old river piers or jetties in the neighbourhood of Liverpool.

Second. The foundations for the river and dock walls were in all positions good, being either on rock (red sandstone) or on boulder clay overlying the rock, so that the solid walls of stone, which are not liable to any deterioration by action of water or organisms therein present, provided more satisfactory wharves than any less resistant structure such as piling, of timber in earlier, or of other materials, in more modern days.

Practically, therefore, the only pile structures in the Mersey Board's section of the estuary are those jetties provided in the neighbourhood of important dock entrances to define the limits of the deep-water fairway, having regard to the banks on either side, and in some degree to serve as guides against which, if need be, vessels entering or leaving might bear. It is necessary that these should be of openwork, in order to prevent as far as possible interference with the ebb and flow of the tidal current.

There are also a few piers acting as abutments to bridges to the great floating landing-stages which at Liverpool provide the means of embarking and landing passengers, mails, etc., from the largest Atlantic as well as coasting and ferry steamers, at all states of the tide. The maintenance in good condition of such stages is an important work, but it does not fall within the scope of the present reference.

In addition to these structures in the river, there are others of somewhat similar construction in the docks in special positions where it has been necessary to bring forward the line of the coping in front of the dock wall, or to close an embayment.

There are also in the estuary at New Brighton, Egremont, Rock Ferry, and New Ferry, on the Cheshire shore, piers, some of considerable length and extent, used partly as promenades, and partly to give access to the bridges of the floating landing-stages of the ferries belonging to the suburban municipalities. These are generally supported on cast-iron braced columns. The older timber structures, fixed and movable, of various designs, which served the ferry traffic at these and other places, at previous periods in the development of the several suburban districts, have now all been dismantled, and their sites are now occupied by new piers and floating stages.

Although piers or wharves of pile or other types are not of great importance in these waters, there is one prominent class of engineering structure in the Mersey, subject to the action of the sea-water and sea-

organisms; that is the dock gates, which, until the great dimensions of some of the entrances demanded gates of a size which could be more conveniently provided in steel-girder work than in wood, have been of the latter material.

The effect of sea-water or the organisms therein on timber is also to be noted from sheet piling of various timbers, which, having been used to form dams for, or to retain material under the foundations of river walls, have had their upper parts left in position above the level of the foreshore, and so exposed to any deteriorating action which exists.

The water of the Mersey estuary is practically ordinary sea-water; the quantity of freshwater discharged by the rivers Mersey and Weaver and minor streams contributing to the estuary water being negligible in proportion to the quantity of sea-water entering the estuary on each flood tide. For the same reason the sewage, domestic and manufacturing, of the great urban areas draining into the estuary cannot be considered to affect the quality of the water in bulk, although certain of the sewers might have some special effect on materials if it happened that important structures existed in the immediate neighbourhood of their outlets. In attaching herein no great importance to the influence of sewer discharges, I do not exclude the possibility of the noxious effect of the same on organisms detrimental to timber, etc.

It follows from the fact that the capacious upper estuary of the Mersey has to receive and discharge its vast tidal contents through the comparatively narrow neck at Liverpool, after passing over the outer and inner banks, that there is always in movement by the current and suspended in its waters a very considerable proportion of sand and silt, which is understood to make it an undesirable habitat for some forms of destructive marine life, including the ship worm, *Teredo navalis*. In any case, that pest cannot be said to cause any trouble in the Mersey, though it has been found in a few cases.

The *Limnoria lignorum* is the only creature which is liable to cause any mischief in the estuary. It occasions a slow deterioration of unprotected soft woods, destroying the surface in successive layers. Its accumulated ravages destroy such timbers in time, but do not cause them to become ineffective for a considerable number of years.

Where "worms" are mentioned in the local notes which follow, it may be taken that the *Limnoria lignorum* is referred to unless otherwise stated.

For the purpose of the present enquiry, the most convenient course will perhaps be to refer to the various materials of which the structures are composed, and to point out in passing which of them give evidence with regard to these injuries.

Greenheart (*Nectandra rodiœi*).—Greenheart timber has been used in the construction of dock gates on the Mersey Dock Estate since well before the middle of last century.

Immersed in sea-water at Liverpool constantly or intermittently, as when between high and low water, neither the water nor any organisms contained in it seem to have any deleterious effect on this timber. This is a commonplace of Liverpool experience, and is unquestionable.

To illustrate its truth, particulars of the life of certain gates of the

Canada Lock may be given. This lock is 100 feet wide, and when constructed in 1857 it furnished the widest entrance in the world having gates. The gates were built entirely of greenheart. Each of the two equal wings of a "pair" of gates was 57 feet long and 30 feet high. The original gates served their purpose regularly until 1896, when in the course of important alteration to the docks in the locality they had to be reconstructed to suit the greater depth. The following remarks on this alteration were made by Mr. Fielden Sutcliffe, the resident engineer for the works, in a discussion at the Liverpool Engineering Society, the 3rd March, 1897, on a Paper on "Dock Gates":—[1]

"Those gates were in active use for 40 years, and I always looked upon them as being among the finest specimens of design and workmanship that it is possible for one to see. I had to take those gates asunder to utilise them on the construction of the new gates that have been provided. The author in his Paper states that a large proportion of the old gate timber was used again. That does not express to my mind in sufficiently strong terms the perfect condition in which those gates were found. I may say that, after the 40 years that they were in use, for all practical purposes they were as good as the day when they were built. When they were rebuilt it was necessary to introduce new timber for all the vertical members on account of the lock having been deepened, not that the old ones were in any way deteriorated; there was no sign of decay about them at all. The several members when parted showed both tenons and mortices to be perfect, thoroughly sound joints, a dead fit, in all parts true and square; there were no joints made slack behind to show a good front, but everything fitting perfectly, tight and sound. The old horizontal ribs have all been put into the new gates, and under ordinary circumstances I should say that they are likely to last as long as the new timber put in with them."

That statement was made in 1897, and now, in 1918, after a total life of 61 years, the gates are still in first-class condition, and are likely to remain so for a great many years to come. The greenheart is, of course, entirely without any cleading or other protection than gas tar.

In 1866 the gates of the 100 feet Alfred Lock, on the Birkenhead side of the river, were built—the heel and mitre posts and bottom ribs of greenheart and the upper ribs and fenders of Baltic pine sheathed in greenheart. In 1914 these gates were damaged by a vessel running into them end-on, and they were put in graving dock for repairs. The greenheart was found to be in excellent condition, and perfectly free from the attack of worms.

The same remarks apply to the greenheart in gates generally in the port. The gates may get out of repair through strains in ordinary operations or through damage by ships, etc., bolts and attachments deteriorate under strains and action of sea-water, but the greenheart remains good so far as decay in sea-water or deterioration by organisms therein are concerned.

The resistant character of greenheart, as compared with other woods,

[1] Transactions of the Liverpool Engineering Society, Vol. xviii, p. 164.

was proved many years ago, and is well illustrated by the case of some timber "paddles" or sluice valves, partly of British oak and partly of greenheart. Whereas the oak is greatly deteriorated by the action of worms, the greenheart remains perfectly sound.

With regard to the use of greenheart timber in jetties, the two on the north and south sides of Canada Basin[1] may be mentioned. These jetties are alike in general construction. The base is of mass concrete in which are laid lines of sluicing pipes, with outlets for removing any deposits of sand or silt from the fairway. The surface of the concrete is laid at about the level of Old Dock sill, which is about 5 feet below mean-water level, and is therefore about 10 feet above low-water level of equinoctial spring tides. The coping level is about 10 feet above high water of such tides The uprights of the timber superstructure are set in the concrete of the base, and the main raking struts are let on to a sole piece, embedded flush in the concrete base. The jetties were constructed between 1879 and 1885, so that they are now between 33 and 39 years old.

An examination of either structure at low-water now shows that it is in all respects practically as sound as when first built. The arrises of the timber are in all cases well preserved. In some of the logs, which had a certain amount of wane at the edges, this defect is preserved in its original form. From the base to about the level of high water of neap tides, say, 12 feet, the timbers generally have a coating of small barnacles—perhaps having a $\frac{3}{8}$ inch projection from the face of the timber—not forming a continuous coating, but with intervals of fractions of an inch between them. When the barnacles are scraped off, the surface of the greenheart is as even as it was when it was worked, except in the case of one or two logs, where there has evidently been a little sapwood, and where slight furrows of decay from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch deep are seen; the ridges between are, however, hard and sound. There is not in these shallow furrows any direct evidence of worm action.

Oak.—Oak was largely used in the construction of dock gates before greenheart became common. There are gates in use in the older central docks of which the timbers are still sound after a period of over 70 years. It was usual to stud the heel posts with copper nails with flat heads so as to cover nearly the whole surface.

The life of the paddles was, from 1843 to 1859, 16 years, but data are not now available of the exact conditions obtaining in the case of these timbers. Probably the paddles were unworked for considerable periods, whereas the gates were constantly worked, and, moreover, they were well looked after in the way of inspection, which in the days of oak gates it was possible to make very complete, as the sills were then all above the level of low water of spring tides, and the recoating with tar was done at comparatively short intervals, while the surfaces, such as the heel-posts, which could not be got at with the tar-brush, were protected, as explained, by copper nails. On the other hand, the paddles had probably not those advantages, and consequently were more open to attack.

Baltic Timber and Pitch Pine.—Baltic timber was used in the earlier

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[1] See Minutes of Proceedings Inst.C.E., Vol. c, p. 19.

dock gates for the upper ribs, but it was frequently sheathed with greenheart to protect it from being damaged by worms. There is still timber of this kind in some of the dock gates which is in good condition after more than 30 years' use.

Pitch pine has not been used under water to any extent except for works of a temporary character or when designed to be so. There are, however, a few cases of its use in permanent works. One such is found in the form of horizontal struts between the greenheart face uprights of the jetty or wharf in front of the river wall at the south side of the Herculaneum entrances. These struts on inspection now are shown to be sound generally, but there is a certain amount of waste or decay on the under surface.

Part of the struts next to the river wall has been sheathed on all sides with greenheart, which, where it remains complete, has protected the pitch pine and suffered no deterioration itself, but the unprotected pitch pine has apparently suffered from the repeated lapping of the water on the rise and fall of the tide and under wind action, so that there is in many cases decay 1 inch or $1\frac{1}{2}$ inch in thickness. There is no decay on the tops or sides of the timber, showing that the injury is probably due to the wear caused by the mechanical action of the water.

It may be pointed out that in some cases where the greenheart sheathing has been broken away from the pitch pine, the damage to the logs is worse at the point where the log enters the masonry of the wall, that being the point where at times the force of the blow from waves is concentrated.

There is no appearance of action by any organisms in this wear or decay. It is also noteworthy that in all the fenders on the face of this jetty, separated by a space of about 2 inches, the wear has not taken place, the explanation, it is presumed, being that there is no room between the adjacent fenders for strong upward action by water.

As regards temporary work, the 12 inches by 12 inches piles of the dam at the north quay of Hornby Dock, across the site of the new 90 feet lock, connecting that dock with the northern extension scheme of docks, were driven in 1908, but owing to the postponement of the scheme the dam was not completed, and pumped out until the works were started again in 1912. The dam is still in use, and as far as can be seen on the inside of it the piles are still in good condition, and there is no sign of worm action.

In the construction of the sluices at the back of the landing stage in 1882 pitch pine was used for temporary dams. Some of the sheeting piles are still in place, and the tops of these, which are dry at low-water, are badly worn.

Elm.—Up to about 12 years ago American rock elm (*Ulmus racemosa*) was used for fenders on gates and jetties. As these fenders have generally to be renewed through wear and tear, it is not easy to arrive at the life of this timber; but in the construction of the river wall north of the North Wall lighthouse in 1864 rock elm was used for the sheet piling of the dams in which the foundation of the wall was laid as "tidework." A length of about 200 feet of this wall has been underpinned recently,

back and front, in the construction of the new 130 feet river entrance lock to the northern extension scheme, and these piles were found (1918) to be quite sound below the level of the beach and at the back of the wall, but considerably decayed above the level of the beach, *i.e.*, where intermittently submerged.

English elm (*Ulmus campestris*) has been used for fenders for about the last 12 years, and has not been attacked by worms so far here, but in most cases the fenders have become worn out, and have perished solely from this cause.

Ferro-Concrete.

The only ferro-concrete under water here is the piling of the wharves at the south-west of the Princes Dock and the north-west of the Brocklebank Branch Dock.

The former was constructed in 1905 and the latter in 1907. No serious deterioration of the structure has so far taken place, though slight repairs have been made in some of the members, generally due to damage by blows. The steel reinforcement is generally not closer to the surface than 1½ inch.

Mass Concrete.

There are no signs of deterioration of mass concrete work in the Mersey Dock Estate. During the construction of the 90 feet lock of the northern extension scheme a length of about 150 feet of the North Wall of the Hornby Dock, built in 1882, was entirely removed in 1914. The concrete was perfectly sound throughout. The base concrete of the north and south jetties, Canada Basin, constantly exposed to sea-water subject to wave-action, remains perfect after about 35 years.

Cast Iron.

There are no cast-iron structures under water on the Dock Estate but on the Cheshire side of the estuary the landing-piers to which the floating stages are connected at New Brighton, Rock Ferry, and New Ferry are supported on cast-iron columns which extend to about lowest low-water. These piers have been in existence for over 50 years in the case of New Brighton.[1] The columns are covered with small barnacles up to a level of about 8 feet above mean sea-level, and they appear to be in sound condition.

THE PORT OF LONDON.

By C. R. S. KIRKPATRICK, M.Inst.C.E.

GENERAL.

For the purposes of this investigation nine structures in the estuary of the Thames were examined; three timber, three iron, and three reinforced concrete structures, see chart, Fig. 9.

[1] See Minutes of Proceedings Inst.C.E., Vol. xxviii, p. 217.

Briefly put, the following are the main points brought out :—

Timber Structures.—The teredo does not occur above Gravesend and timber structures above that point are practically immune from attack by sea organisms. Such structures, as a whole, last until the general wasting of the timbers reduces the strength below the required limit, but in jetties the deck and joists under it have a shorter life than the remainder so that these are the first parts to require renewal. The Northfleet Deep Water Jetty, constructed of Memel fir over 50 years ago, is still in use though in a dilapidated condition and, apart from the renewal of deck and joists and the making good of damage done by shipping, few repairs have been carried out. It appears to be advisable to use small section nails for fastening down the decking, as the heavy spikes customarily in use damage the timber and hasten decay. Horizontal surfaces between timbers where moisture can lie should be avoided as far as possible.

Iron Structures.—Cast-iron structures appear to have an almost indefinitely long life. The Royal Terrace Pier, at Gravesend, and the Mucking Lighthouse, at Thames Haven, both constructed of cast-iron columns about 70 years ago, are still in good condition generally. Where connections with different metals or with different types of the same metal occur below high-water deterioration does take place and is somewhat rapid, and such connections should be avoided. Wrought iron is most vulnerable about high-water level. Below half-tide level and away from contact with other metals it is found to be as new after 70 years.

The one example seen of rolled steel joists was under the deck of Southend Pier, and these have suffered seriously after 26 years' exposure.

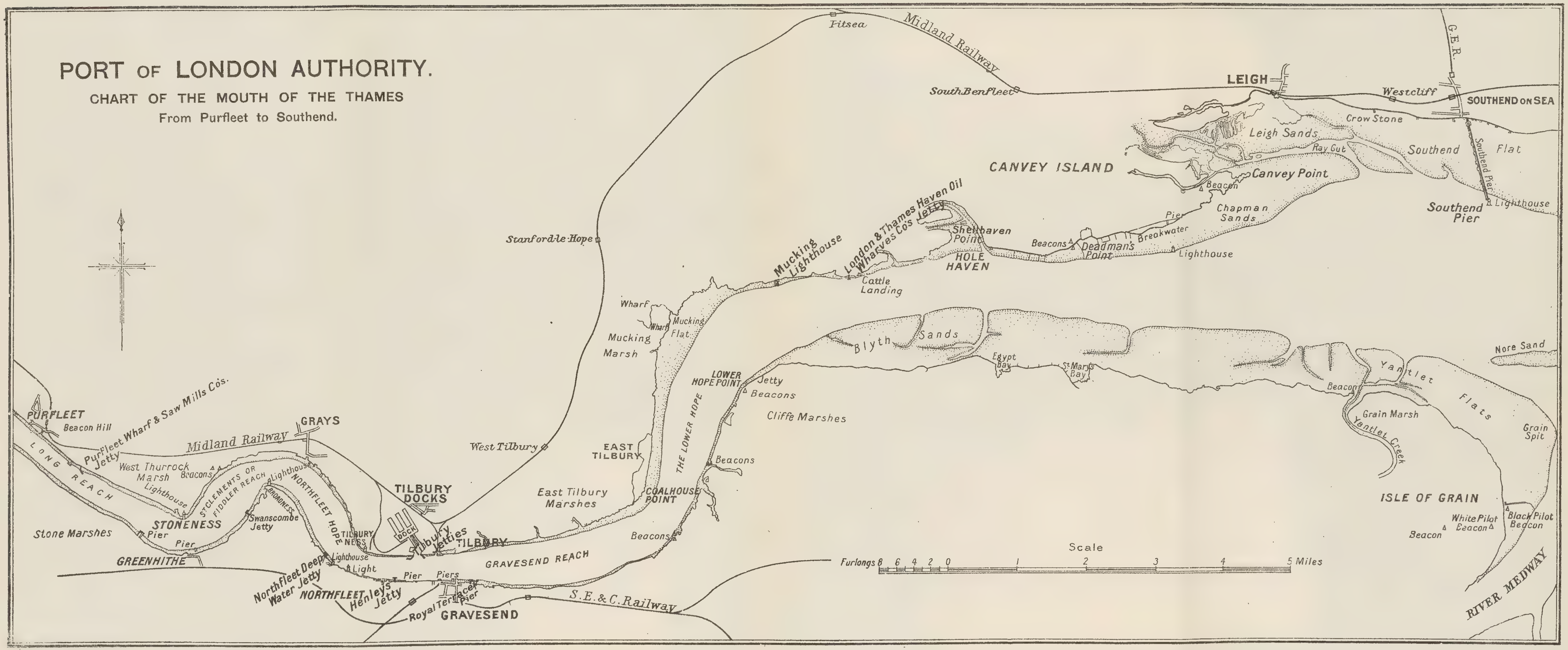
Reinforced Concrete Structures.—The three reinforced concrete jetties examined were all approximately of the same age, the oldest having been constructed about 12 years ago.

The most striking feature of the examination was that no serious deterioration was found below high-water level. In the first jetty little deterioration was to be seen in any part. In the second about one third of the beams carrying the deck had been repaired on the under surface. In the third nearly all the deck beams were very seriously deteriorated It was found that practically all this deterioration was due to insufficient cover of the steel, so that it can only be said to show the necessity for great care in ensuring that the steel is fully protected.

The following suggestions in connection with the design and construction of reinforced concrete structures exposed to sea action are made :—

Structures should be designed with the smallest number of members practicable ; thus a group of uprights incased in a cylinder and forming one single column is preferable to a number of smaller uprights. The greatest care should be taken in respect to workmanship generally and to see that all steel is well protected by the concrete. No reinforcing bar in any important beam or column should have less than $1\frac{1}{2}$ inch of cover, and the correct placing of the stirrups requires the utmost attention. The use of flat stirrups should be avoided. Iron bolts or plates for the attachment of external items should not be embedded in the concrete.

FIG. 9.


PORT OF LONDON AUTHORITY.
CHART OF THE MOUTH OF THE THAMES
From Purfleet to Southend.
Pitsea
Midland Railway
South Benfleet
LEIGH
G.E.R.
Westcliff
SOUTHEND ON SEA
Crow Stone
Leigh Sands
Ray Gut
Southend
Flat
Southend Pier
Lighthouse
Southend Pier
CANVEY ISLAND
Canvey Point
Beacon
Chapman Sands
Pier
Breakwater
Lighthouse
Beacons
Deadman's Point
Shellhaven Point
HOLE HAVEN
London & Thames Haven Oil Wharves Co's Jetty
Mucking Lighthouse
Cattle Landing
Stanford-le-Hope
Wharf
Wharf
Mucking Marsh
Mucking Flat
Blyth Sands
Egypt Bay
St Mary's Bay
Yantlet Flats
Nore Sand
Beacon
Grain Marsh
Yantlet Creek
Grain Spit
ISLE OF GRAIN
White Pilot Beacon
Black Pilot Beacon
Beacon
RIVER MEDWAY
LOWER HOPE POINT
Jetty
Beacons
Cliffe Marshes
THE LOWER HOPE
Beacons
EAST TILBURY
COALHOUSE POINT
East Tilbury Marshes
Beacons
West Tilbury
PURFLEET
Beacon Hill
Purfleet Wharf & Saw Mills Co's.
Purfleet Jetty
GRAYS
Midland Railway
West Thurrock Marsh
Beacons
Lighthouse
LONG REACH
ST CLEMENTS OR FIDDLER REACH
Lighthouse
BROADNESS
NORTHFLEET HOPE
Swanscombe Jetty
STONENESS
Stone Marshes
Pier
Pier
GREENHITHE
TILBURY DOCKS
DOCK
TILBURY NESS
Tilbury Jetties
TILBURY
Lighthouse
Light
Northfleet Deep Water Jetty
NORTHFLEET
Henley's Jetty
Pier
Piers
Royal Terrace Pier
GRAVESEND
GRAVESEND REACH
S.E. & C. Railway
Scale
Furlongs 8 6 4 2 0 1 2 3 4 5 Miles

IRON STRUCTURES.

Introductory.—Three iron structures in the estuary of the Thames were examined. The Terrace Pier, at Gravesend, 73 years of age, The Mucking Lighthouse, near Thames Haven, 66 years of age, and Southend Pier, 26 years of age. All three are built of cast-iron columns with wrought-iron or steel additions, and generally the same effects after the lapse of time are to be observed.

Cast iron, itself, is evidently almost unaffected by Thames estuary water, but where connections with wrought iron occur below high-water level deterioration is to be expected. This deterioration may affect either the wrought iron, the cast iron or both, and is probably due to some electrolytic action, rendered possible by some slight difference in the composition of the metals. Examples of such deterioration are seen:—

(1) In the Terrace Pier—where the wrought-iron tie rods are attached to the cast-iron columns.

(2) In Mucking Lighthouse—where the cast-iron members are fastened with wrought-iron bolts.

(3) In Northfleet Deep-Water Pier—where the timber uprights are secured in the cast-iron footings by wrought-iron spikes. Deterioration of this type in the case of the Southend Pier is so far very slight.

This action does not take place above the level of high water. This is shown most clearly in the case of the Terrace Pier where the upper attachments are all in good condition, although some of them are 73 years of age, while many of the lower attachments fixed only 23 years ago are very much corroded. The difference in the way in which these lower attachments of tie rods fixed in 1894 in the Terrace Pier have become deteriorated is very striking.

Wrought iron itself in every case showed most corrosion about high-water level, but deterioration of this type is much slower than that referred to above; thus the 1894 tie rods in the Terrace Pier and also the ties, presumably of steel, in Southend Pier are, so far, only slightly corroded, while the original tie rods in the Terrace Pier, 73 years of age, and the hand grips in the Mucking Lighthouse, 66 years of age, have lost 25 per cent. to 50 per cent. of their substance locally, in the neighbourhood of high-water level. The old tie rods in the Terrace Pier, although over 70 years of age, are practically unaffected below half tide level.

The cast iron girders in the Terrace Pier, which are some 8 feet above high-water level, and are 73 years of age, are coated with rust, but there is no evidence to show that they have lost any serious amount of substance, while the rolled steel joists in a similar position in Southend Pier, 23 years of age, have suffered considerably.

Royal Terrace Pier, Gravesend.

Description.—This pier, which is a T-shaped structure on cast-iron columns, is now used as the Pilot station at Gravesend for the Port of London. It was built under the direction of Mr. J. B. Redman, C.E. in 1844. It is, therefore, over 70 years of age. The approach measures 250 feet × 30 feet and the head 90 feet × 30 feet. A photograph of the

pier is attached, see Plate V. An interesting account of the construction is given in *The Illustrated London News* for the 5th April, 1845, from which the following particulars are taken.

" The bases of the columns are level with low water of spring tides, standing upon a brick and stone foundation; which was got in in the following manner :—Cast-iron cylinders, 6 feet in diameter, and $\frac{5}{8}$ of an inch thick, each ring being formed of four segmental plates, those of each ring breaking joint over another, were sunk down through the bed of the river to the chalk substratum, excavating the ground from within as they sank, additional lengths being added as required ; they thus formed caissons, or, more properly, miniature coffer-dams, the top being always kept above high-water level.

The cylinders being sunk to the required depth upon the solid substratum, and the bottom levelled, a floor was formed of brickwork, Roman cement, and plain tiles ; this precaution being taken to keep out the land springs. The principal novelty in these foundations is, applying iron cylinders in such a way as to exclude the flow of a rapid tideway, thus enabling the men to work at nearly all times of tide, and when the bottom is once got in, at any time ; thus dispensing with a large amount of pumping, which is proved by the fact that these foundations, at so great a depth and with so large a head of water, were kept clear of water by hand-pumps, and a steam engine dispensed with. And, we believe this to be the first instance of cylinders being applied so as to exclude the tidal flow of a rapid river, making them effect the same object as a coffer-dam ; nor, is it believed that cylinders have before been applied for the purposes of foundations for a structure of this kind on so large a scale."

On these foundations are erected the twenty-two cast-iron columns which carry the superstructure (thirteen under the head and three rows of three each under the approach). These columns are 28 feet long, 4 feet in diameter at the base and 3 feet at the top and as they weigh $9\frac{1}{2}$ tons each the metal must be about $1\frac{1}{2}$ inch thick. Wrought-iron tie rods about $2\frac{1}{4}$ inches diameter were fixed to some of the columns as shown on the diagrams attached. The tops of the columns of each row are connected by a cross brace bolted to the caps. The cast-iron girders which support the deck, etc., rest on these braces.

These girders, of which there are nine, are about 55 feet in length and 3 feet in depth and they are cambered $1\frac{1}{2}$ inch to allow for deflection. The sectional area is much reduced at the ends, both in flanges and web.

The pier was not the financial success its original owners hoped for, and after some years it passed into the hands of the Receiver of the Court of Chancery, and is said to have been left derelict for 30 years. About 1893, a company formed by the Gravesend pilots, called The Royal Terrace Pier Co., acquired the property and had it put in a proper state of repair and altered to suit their requirements.

The pier originally cost £14,000 and a further £7,000 was spent in 1894 in repairs and the provision of pontoon and bridge, shelters on pier, etc.

Exposure.—This pier is situated at Gravesend on the south side of the

PORT OF LONDON.

Royal Terrace Pier, Gravesend.

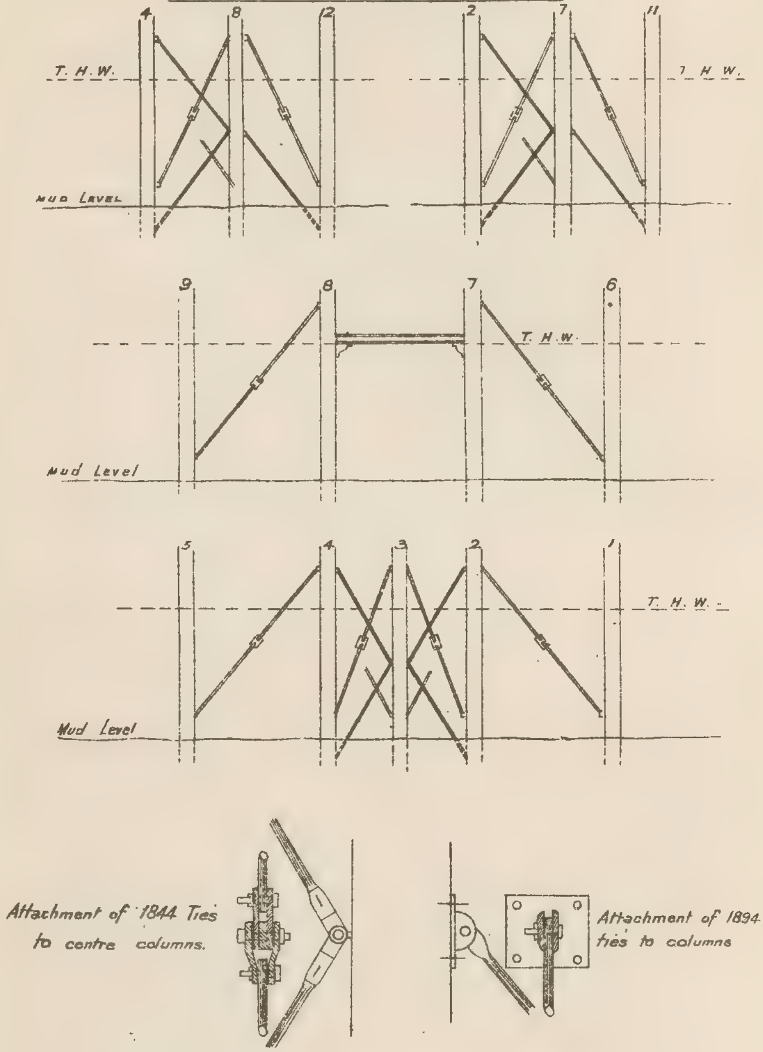
Southend Pier.

FIG. 10.

ROYAL TERRACE PIER GRAVESEND

DIAGRAM SHOWING COLUMNS AND CONNECTIONS

Ties shown in Solid Black fixed 1844
Ties shown in Outline fixed 1894



river Thames, which here runs east and west. The structure is exposed down to the mud at low water of spring tides.

The composition of the water here varies from about 75 per cent. sea-water at high water to 50 per cent. at low water.

Deterioration.—There is no sign of any settlement of foundations. The columns, which were last tarred in 1894, are, as far as can be seen, still in very good condition. For about 18 inches above the level of the mud the columns are encrusted with patches of some material. Under each of these patches the metal is soft for varying depths, but never exceeding $\frac{1}{4}$ inch.

For about 3 feet below T.H.W. the tar has washed off more than elsewhere and some slight rusting is apparent. Above H.W. mark and between 3 feet below H.W. and 18 inches from the mud the columns show practically no deterioration, except in the case of two columns in which there are holes some distance above the ground level. The water draining out of these holes while the level of the tide is below them induces a growth of shell-fish and incrustation and under these the metal has softened, but never more than $\frac{1}{4}$ inch deep.

A number of wrought-iron diagonal tie rods 2 inches in diameter which were fixed during the reconstruction in 1894 run from the bottom of one column to the top of the adjacent one, as shown on diagram, Fig. 10. These rods are attached to the columns by cast-iron plates fitted with lugs to take the eyebolt of tie bar. Each plate is fixed to its column by four studs. The upper plates are about 5 feet above H.W.S.T. and show practically no deterioration. There are fourteen lower plates just above the mid level. Three of these, *viz.*, two on column No. 3, and one on column No. 4, including plate and lugs, studs, eyebolt, pin and cotter, show no deterioration.

Seven, *viz.*, two on column No. 2, one each on columns Nos. 4, 5, 7, 8, 9, were found to be corroded as follows:—Adjacent faces of lug and of eyebolt were soft $\frac{1}{4}$ inch deep; outside of lug itself softened for $\frac{1}{4}$ inch; the 2-inch tie bar was reduced to about $1\frac{1}{2}$ inch for a few inches above the eye. The plate itself, the studs, the head and point of bolt, including the cotter, were as new.

The attachment on column No. 11 was corroded in a different fashion, and in this case the lugs and eyebolt were untouched, but the bolt and cotter were eaten away. The bolt head was (after the softened metal was removed) about half its original size and the cotter was reduced to about half its thickness. On removal of the soft black material in which it was enveloped the cotter showed its fibrous structure and was quite bright. The heads of the two upper studs in the cast-iron plate were as new, while the heads of the lower two were corroded to half size. It will be noticed that in this case the parts which were corroded in the previous group were sound, while the parts which were sound in the others were now corroded.

Column 12 showed another variation, as in this case the eyebolt, the lugs, the bolt itself, the cotter and the two lower studs were softened, leaving only the top of the plate and the two upper studs unaffected.

In the case of the attachments of the tie rods, fixed in 1844 to the

centre columns, the two pairs of wrought-iron plates forming the sides of the links and the eyebolt fixed to the columns were considerably corroded, while the bolts, cotters and ends of the ties themselves were unaffected.

The wrought-iron tie bars themselves fall into two groups, *viz.*, those which are part of the original structure and those fixed in 1894. The former have suffered considerable corrosion about high-water level, while the part above the reach of the tide and the part below half-tide level showed practically no deterioration. As the lower connections were buried in the mud they were not available for examination. The bars fixed in 1894 were practically free from corrosion. About midway on each of these bars there is a screwed coupling and in every case this was as new and the threads on the bar outside the coupling were still clear and sharp. All these rods had been tarred in 1894.

The cast-iron girders which support the deck were also tarred in 1894, but are now coated with rust about $\frac{1}{4}$ inch deep in places at the shoreward end. They are fully exposed to the damp air rising from below.

Mucking Lighthouse.

Description.—The Mucking Lighthouse was designed by Mr. J. Walker, the Engineer-in-Chief to Trinity House Corporation. It was built in 1851, and the substructure consists of seven cast-iron columns bedded about 2 feet into the gravel, which lies about 46 feet below low water. The columns are stayed above low water by horizontal and sloping cast-iron braces. There has been no change in the structure since erection and no repairs through defects have been required.

Exposure.—The lighthouse is situated on the north bank of the river in Sea Reach. It is exposed to alternate wetting and drying from the action of the tides. The water here is practically normal sea-water.

Deterioration.—Above the level of high water the structure has been kept well painted and there is no evidence of corrosion. In normal times it is painted with Torbay paint every third year. Between high water and low water the structure is normally coated with a special marine black composition every year. This has had to be omitted for the last three or four years, and so at the present time this coating has disappeared from the lower part and below half-tide level the iron is covered with acorn shells, mussels, and seaweed. The cast iron generally is hard and sound, but in places at all levels below high water there are soft patches, but these are never as much as $\frac{1}{8}$ inch deep. For a few feet about high-water level the columns appear rusty beneath the tar, but the rust is only about $\frac{1}{8}$ inch deep. The stays are connected to the columns by flanges which are fastened with wrought-iron studs. In some cases the heads of these studs are badly corroded, this condition being most marked at the lower levels, but generally they are only slightly wasted and in some instances they are as new. Wrought-iron grips to form a ladder are attached to one of the columns; these grips have been eaten away considerably, close to the cast iron, just above and below high-water level, so that the cross section of the wrought iron has been reduced about 25 per cent.

Southend Pier.

Description.—This pier, the property of the Southend Corporation, has a total length of about 6,850 feet, of which the outer 450 feet was added in 1898 at a cost of £18,000, the inner 6,400 feet having been completed in 1891 at a cost of £80,000. In general the pier is carried on rows of three cast-iron columns, the rows being 30 feet apart, these columns are braced together with steel ties. Longitudinal steel girders span from row to row and transverse girders placed on these carry the deck. In normal times the ironwork is tarred down to low-water level every three or four years.

Exposure.—The pier is situated at Southend-on-Sea on the north side of the estuary of the Thames in a very exposed position, and is alternately wet and dry from the action of the tides. The water here is normal sea-water.

Deterioration.—It is now some 6 or 7 years since the ironwork was last tarred, and although the upper part of the structure down to about three feet below high water is still generally coated with this material, below this down to low-water level the tar has disappeared and everything is thickly coated with acorn shells and mussels. On removal of some of the shellfish the metal underneath was found to be hard and good and no corrosion was observed. Small patches which were free from the shellfish were noticed to be shining as if polished by the sand carried past by the water. About high-water level, from about 2 feet above to 2 feet below, the greatest corrosion of tie rods and columns was noticed, but this was only slight, and especially slight on the columns. Above this level the columns show no corrosion, but the longitudinal girders show some rust and the transverse girders under the deck are badly oxidised, nearly all the tar having disappeared from these. The illustration, Plate V., shows the columns of the pier.

TIMBER STRUCTURES.

Three timber structures were examined. The Northfleet Deep-Water Jetty, built of Memel fir in 1866; the Port of London Authority's Jetties, at the entrance to Tilbury Docks, built of pitch pine in 1886, and the Purfleet Saw Mills Co.'s Jetty built of karri wood in 1899. No serious damage by any organism was detected, and these structures seem likely to last until they succumb to general decay. The greatest external wasting of the timbers takes place between high-water level and half-tide level, but such timbers remain sound internally. A more serious type of deterioration, in pine timbers at least, takes place above high-water level, so that the deck and joists under it are always the first parts to require renewal. This decay occurs where the moisture collects between the horizontal surfaces of timbers, and quickly involves the destruction of the whole timber.

Dr. Willoughby, the Medical Officer of Health for the Port of London, who has for many years taken an interest in the marine life of the estuary, informs me that he has found the teredo, and also timber damaged by it, below Gravesend, but never above. He has also dredged

specimens of what he believes to be limnoria from the neighbourhood of the Chapman Lighthouse in Sea Reach.

Northfleet Deep-Water Pier.

Description.—This pier is the property of the Northfleet Coal and Ballast Co., Ltd. The original jetty consisted only of that part through which the section B.B., Fig. 11, is taken, and was built in 1866. The extension on the east side of this was built in 1872 and the remainder in 1875, all being constructed of Dantzic or Memel fir. As shown on the accompanying print, Plate VI., although most of the piles are of timber driven in the usual way, a number in the front part of the pier consist of cast-iron screwed footings, in which timber uprights were stepped just above low-water level.

Exposure.—This pier is situated on the south side of the river at Northfleet, and is used by large sailing-ships and steamers chiefly for loading chalk. The water here may be taken as varying between 75 per cent. sea-water at high water and 50 per cent. sea-water at low water. There is an effluent from the Northfleet Paper Works discharged into the river immediately above this jetty, and to this is attributed the fact that there are no shellfish or weeds on the timbers. They are all comparatively clean.

Deterioration.—There is no evidence of damage by any organism. About low-water level the timber is soft, but not greatly wasted. Above high water the piles look good and fresh. The level where the greatest external deterioration has occurred is about 6 feet below high water, where many of the timbers are wasted away to half their original size. Their appearance suggests that the timber has softened and been washed away the harder portions and knots being left projecting, as is shown on the attached photographs.

None of the piles have been renewed since the jetty was built, but it was found necessary in 1897 to renew the bearers under the deck in the original jetty, i.e., the part through which Section B.B. is taken. Some of the timber taken out was, even then, after 31 years' service, in good condition.

The timber uprights stepped in the cast-iron screw piles are fastened with wrought-iron spikes driven through holes in the cast-iron. The heads of these spikes are round, 1 inch diameter, and many of them are as new, others have completely changed to rust, about 2½ inches diameter, as seen in specimens sent. The cast-iron piles themselves were all uncorroded as far as could be seen. There was nothing to show why some of the spikes corroded and others did not. It is suggested that it is due to electrolytic action, rendered possible by some slight difference in the composition of the metal.

Jetties at Tilbury.

Description.—These jetties are situated at the entrance to Tilbury Docks, and the older parts were built of pitch pine in 1886. The lower jetty is about 350 feet in length and 45 feet in width. The upper jetty was originally about 250 feet in length, but it was extended in 1905.

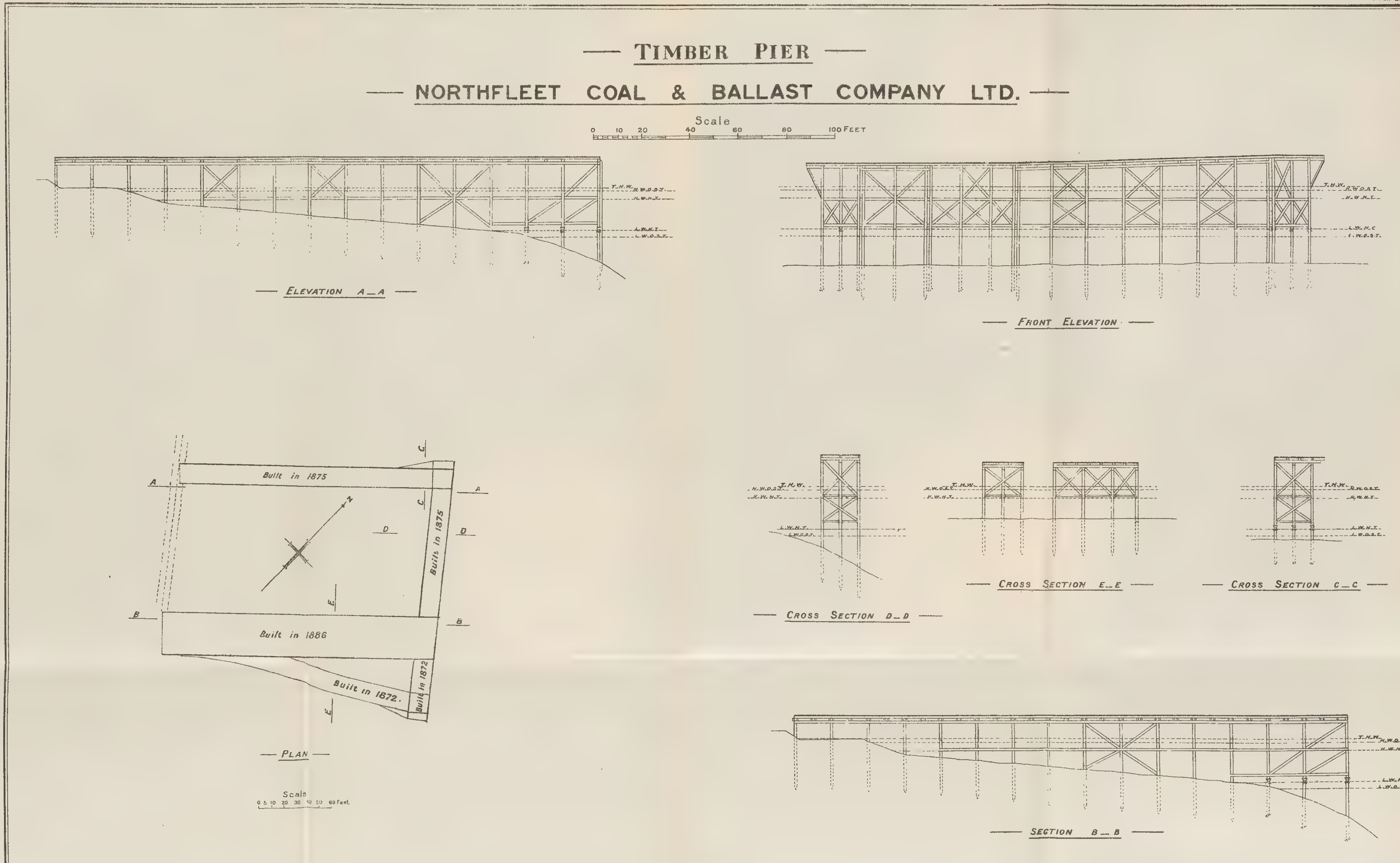
Exposure.—These structures lie on the north side of the river at

PORT OF LONDON.

NORTHFLEET DEEP-WATER JETTY.

NORTHFLEET DEEP-WATER JETTY.

FIG. 11.


TIMBER PIER
NORTHFLEET COAL & BALLAST COMPANY LTD.
Scale
0 10 20 40 60 80 100 FEET
ELEVATION A_A
FRONT ELEVATION
Built in 1875
Built in 1875
Built in 1886
Built in 1872.
Built in 1872
PLAN
Scale
0 5 10 20 30 40 50 60 Feet
CROSS SECTION D_D
CROSS SECTION E_E
CROSS SECTION C_C
SECTION B_B

Tilbury, and are exposed to alternate wetting and drying from the rise and fall of the tides. The composition of the water varies generally from 75 per cent. sea-water at high water to 50 per cent. at low water.

Deterioration.—The timber below half-tide level is still in good condition. The greatest wasting has taken place between high-water level and half-tide level, where some of the timbers have deteriorated considerably. Above high water level the timber looks good externally, but in cases of repairs it is found to be largely unsound. The deck and the joists under it were renewed in 1912, that is, after 26 years' service. It was observed then that the large iron spikes which fastened the decking to the joists had damaged the timbers considerably and were suspected of having hastened decay. In fastening down the new deck small section long nails were used.

The iron fastenings are generally coated with rust, but they do not appear to have suffered any serious loss of substance; those between high-water level and half-tide level have suffered most; below half-tide level corrosion of the iron is slight and the nuts can still be screwed off the bolts.

The only organism seen on these structures was *Ligia oceanica.* In appearance it is like a large wood louse. This creature takes refuge in any crevices it can find, between timbers, etc., and enlarges these spaces to suit its convenience, but it does not appear to do any serious damage. It grows to about 1½ inch in length.

Karri Wood Jetty at Purfleet.

Description.—This jetty, which is the property of the Purfleet Wharf and Saw Mills, was constructed about 1899. It is 50 feet wide, and extending parallel to the river bank for about 300 feet, is connected to the shore by a curved approach about 350 feet in length. There is a depth of about 24 feet at low water alongside. The jetty carries three lines of railway and crane rails in addition.

The whole structure, including deck, is constructed of West Australian karri wood (***Eucalyptus diversicolor***), the cost of this wood at time of construction was about double that of pitch pine. It is built up of piles, braces, struts, walings, etc., in the usual fashion for timber jetties. It is equipped with four electric cranes, weighing about 30 tons each, besides a number of locomotive steam cranes.

Exposure.—The jetty is situated on the north bank of the river near Purfleet, and is subject to the alternate wetting and drying brought about by the rise and fall of the tides. The composition of the water here varies from about 50 per cent. sea-water at high water to 25 per cent. at low water. The water is somewhat affected by the discharge of the effluents from the London County Council outfalls at Barking and Crossness and from the North Kent Sewage works in Long Reach.

Deterioration.—From about half-tide level down to low water the timber is perfectly hard and sound and shows no cracks. From high-water level to about half-tide level there is a scum of soft decayed timber on the surface of all the members. This is generally a mere skin and in no case more than ¼ inch thick. It appeared to be at its worst about

3 feet below high water. From high-water level to deck level the timber appeared as new, except that a great number of the struts show longitudinal cracks for about half their length and always the upper half. These cracks never go through the timber but seem to extend in to the centre. The same strut is never cracked in more than one plane. The tops of the piles show similar cracks, but not to the same extent. Curiously enough no cracks appear in the half-timber braces. The decking is sound and hard, and considering the traffic to which it is subjected it shows little wear. The iron fastenings are generally in good condition. Of those below high water only about 20 per cent. show any corrosion at all, and the action in these is only slight. Above high water the exposed iron is all covered with a coat of rust, but is not yet deeply corroded. There are no signs of damage by any organism.

REINFORCED CONCRETE STRUCTURES.

Three reinforced concrete structures were selected for examination. Messrs. Henley's Jetty at Gravesend, built in 1905; Swanscombe Pier, built in 1906; and Thames Haven Jetty, built in 1907. These are among the oldest reinforced concrete jetties erected in the Thames estuary, but as the oldest of them is only 12 years of age, any conclusions formed as to the lasting properties of the material could only be of a negative character.

Serious deterioration was found only above high-water level, and could nearly always be traced to faulty construction. Thus the information obtained from this investigation, while not at all reassuring, can hardly be said to do more than prove the necessity for great care in the construction of reinforced concrete structures, especially in ensuring that the steel is well covered by the concrete. No serious deterioration was found below high-water level.

In both Messrs. Henley's Jetty and the Swanscombe Pier greater deterioration has taken place in the approach than in the pier itself, which is probably due to the extra traffic over these portions. It is not suggested that the deterioration is caused by the traffic, but that deterioration having once begun is accentuated by the strains produced by traffic.

Investigations into the cause of cracks in reinforced concrete structures were undertaken recently by the American Bureau of Standards, and the results are published in No. 18 of their Technologic papers. Experiments showed that the cracking of the concrete is due to the mechanical pressure exerted by the corroding steel. This pressure was measured and found to reach values up to 4,700 lbs. per square inch. If, then, any part of the steel in reinforced concrete is exposed to oxidation, cracking of the concrete follows, exposing further metal, and ultimately, if the process is allowed to go on, the destruction of the whole structure is inevitable.

It is known that iron immersed in water from which the air is excluded does not rust, and also that during the drying of the wet metal corrosion is very rapid. It is probably to these two properties that the

different rates of deterioration of reinforced concrete above and below high water level is due.

Above high water, where the concrete cover is thin, moisture will find its way in to the steel in wet weather, and drying out during the fine periods will produce corrosion and crack the concrete. Below high water, on the other hand, the moisture will not have time to dry out between the wettings, and thus the steel is protected from those conditions which lead to rapid corrosion.

It would thus seem that the amount of cover required in external reinforced concrete structures should be either sufficient to exclude all water and air from the steel, or sufficient to prevent the moisture from drying out in the longest dry periods to which the structure will be subjected.

If this theory be correct the coating of reinforced concrete with any waterproofing material should be a powerful factor in the prevention of the corrosion of the steel. The comparative absence of deterioration in the case of the Thames Haven Jetty, which is more or less saturated with oil, is confirmatory of this opinion.

Messrs. Henley's Jetty at Gravesend.

Description.—The construction of this T-shaped jetty was completed in 1905. The head is 100 feet in length, with a depth alongside of only a couple of feet at L.W.S.T., and the approach is 180 feet in length. The super-structure is carried on columns 2 feet 6 inches diameter, which in turn are supported on piles driven into the bed of the river. The piles were driven to a set of ½ inch for ten blows of a 30-cwt. hammer, falling 5 feet. In addition to the deck beams, there is only one set of braces; these are at a few feet above half-tide level, and all are horizontal. There are no diagonal braces. All members were constructed *in situ*. The reinforcement was carried out on the Hennebique system, and the proportions of the concrete used were 27 cubic feet gravel, 13½ cubic feet sand, and 6 cwts. cement. In the case of the piles the cement was increased to 7 cwts. There is a crane road, 4 feet 8½ inches gauge, down the west side of the approach, and a 2 feet gauge railway down the east side. The loads this jetty was designed to carry are: on 4 feet 8½ inches gauge, 28 tons on four wheels, with a maximum of 18½ tons on one wheel; on 2 feet gauge, 7 tons distributed on four wheels; on deck, 5 cwts. per square foot. The crane is worked electrically. The supply—250 volts—was drawn from an overhead wire, with return through rails, until 1913, when a 500-volt circuit was established, with an insulated return wire. The deck is 5 inches thick, reinforced with $\frac{5}{16}$ inch steel, the spacing being 6½ inches for the transverse bars and 10 inches for the longitudinal bars.

A vessel collided with the western end of the head in 1907, and fractured one of the deck beams; this was cut out and replaced. A more serious damage to the same parts occurred in 1908, when a vessel carried away her moorings from a wharf higher up the river and drifted on to the end of the jetty. On this occasion the two west end columns were fractured, together with several beams and part of the deck. The

damaged portion was removed and rebuilt. In the reconstruction the two western columns were increased from 2 feet 6 inches to 3 feet 6 inches in diameter. No other action was taken to prevent similar damage in future.

Exposure.—The jetty is situated on the south side of the Thames at Gravesend, and is subject to the alternate wetting and drying brought about by the action of the tides. The water here varies from about 75 per cent. sea-water at high water to 50 per cent. at low water.

Deterioration.—In 1916 the owners of this jetty noticed that some deterioration was going on, and, on the advice of the concrete specialists, the whole structure down to low-water level was given two coats of wood naptha and gas tar.

When the jetty was examined for the purposes of this investigation in October, 1917, it was found that very serious deterioration had taken place in the beams supporting the deck, and a careful examination was made of each beam.

In the moulding of the beams the stirrups were evidently allowed to fall below the steel bar, and in many cases to rest on the bottom of the forms, while the upper parts appear to have spread out towards the sides. The result of this is that the stirrups have corroded both at the lower ends and up the sides of the beams. The corrosion of the lower ends has cracked the concrete underneath, thus exposing the reinforcing bars locally, which, by rusting in turn, have cracked many of the beams for their whole length, while the corrosion of the upper parts has forced off slabs from the sides, so much so that in many cases whole sides of the beams have become detached. This demonstrates clearly that these flat stirrups should not be used in reinforced work. Many of the beams have reached such a condition that they will require renewal at an early date.

In the transverse beams situated under the deck of the T-head, deterioration has taken place chiefly in the beams which span from column to column, and always close up to the columns. This suggests that there has been some slight movement of the columns. Practically all the beams under the deck of the approach have deteriorated to some extent, and the damage is generally worse as the shoreward end is approached.

The deck itself, as far as could be seen through the tar, is in good condition. There are slight transverse cracks in many of the bays, but no corrosion of the steel was detected.

The beams at half-tide level showed many rust spots, but these had the appearance of having become sealed up. No cracks were observed. The columns all appeared to be in good order. Slight spaces between the upper rings were observed in one or two places in the columns under the T-head, which strengthens the conclusion before mentioned that there had been some slight movement.

Timber fenders are attached to the columns by iron plates let into the concrete and projecting outwards to take the bolt passing through the fender. These have rusted, and, by the expansion, have burst off the concrete, and in some cases have come adrift. This is most noticeable at the upper levels.

PORT OF LONDON.

General View of Swanscombe Pier.

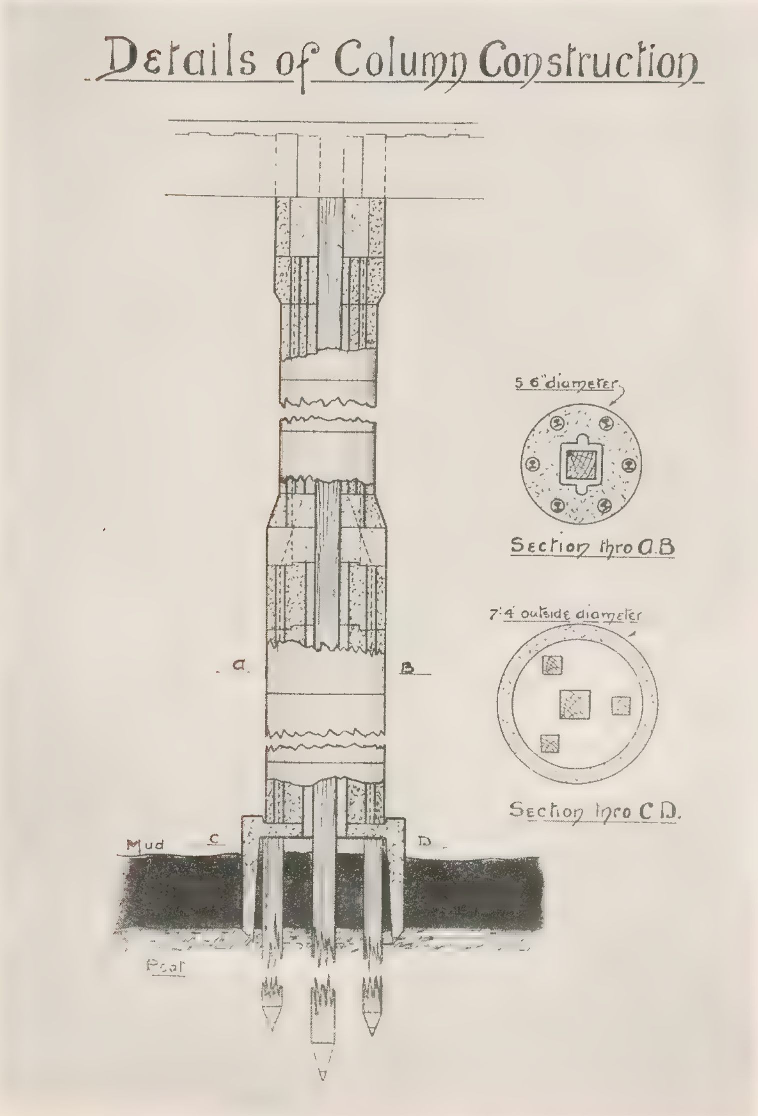
Ready-made longitudinal beams placed in position. Swanscombe Pier.

PORT OF LONDON.

CONCRETE STRUCTURES, SWANSCOMBE PIER.

Mode of construction of columns of reinforced concrete.

PORT OF LONDON.



CONCRETE COLUMNS, SWANSCOMBE PIER.

Swanscombe Jetty.

Description.—This jetty, which is the property of Messrs. The Associated Portland Cement Manufacturers (1900), Ltd., was constructed in 1906 to the designs of Mr. C. Percy Taylor, the chief engineer to the company.

The structure is L-shaped in plan, with a frontage of 130 feet and a depth alongside of 17 feet at L.W.S.T. It is carried on thirty-two columns arranged in pairs at 25 feet centres transversely and 28 feet centres longitudinally, except at the angle (see general view, Plate VII). Each column is supported on four timber piles; three of these are cut off a few feet below the bed of the river, and on these the lowest block of the column is placed, while the fourth pile extends upwards through the centre of the column (see illustration, Plate IX). The columns are built up of circular blocks, 5 feet 6 inches diameter, below low water, and 4 feet 6 inches above. The blocks were strengthened by having rings of $\frac{3}{4}$-inch steel, about 4 inches diameter less than the blocks, built in every 8 inches. Six holes near the circumference were cast in each block, and through these old rails, weighing 30 lbs. per yard, were threaded when the column was built, and finally all was grouted up. The portion of the column below low water was built above the water, block by block, around the central pile, with strong mortar joints between, and then the whole section was lowered into position (see Plate VIII). On this base the remainder of the column was then built up. Each pair of columns is connected by a cross-brace, just above the low-water level. These braces were built ashore. Between the last three pairs of columns at the outer end of the pier there is in addition a diagonal strut built *in situ.*

Under the deck run nine rows of longitudinal beams, 12 inches by 36 inches (see illustration, Plate VII). They were constructed ashore in lengths to span from column to column, and they were connected up across each pair of columns by a cross-beam, built *in situ.* The longitudinal beams are also connected by a stiffener midway between each pair of columns. Kahn bars were used in the reinforcement of the main beams, and also ordinary round bars, as shown in the accompanying print, Fig. 12 The deck, which is in panels generally 11 feet by 4 feet, is 5 inches thick, reinforced with Johnston's lattice. The concrete was made from Thames ballast, screened and broken to $\frac{3}{4}$ inch, the proportions being $1\text{–}2\frac{1}{8}\text{–}3\frac{1}{8}$. The designed minimum cover was $1\frac{1}{4}$ inch.[1]

Exposure.—This jetty is situated on the south side of the river at Swanscombe, in the bight below Greenhithe. It is used by steamers up to 2,000 tons and barges for loading cement. It is exposed to tidal action. The water varies from 35 per cent. sea-water at low water to 60 per cent. at high water.

Deterioration.—There is no sign of any settlement of the foundations. The columns were generally in good condition, as far as could be seen externally. The cement bedding between the blocks had been washed out in a few cases, and a few wet patches on the columns indicate that the water is forced into some vacant space at high water and oozes out at low

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[1] See "Transactions of the Concrete Institute," Vol. iii, p. 178.

water. The junctions of the horizontal cross-beams, which were built ashore and fixed in as the work proceeded, were generally good, but in a few cases some of the filling between the braces and the columns has been washed out. The diagonal cross braces were built *in situ*, and at the junction of these with the columns and with the horizontal braces it was possible in two or three instances to insert a knife-blade some inches into the joint. Some of these junctions were opened out and examined, but the openings referred to were found to be only a couple of inches deep, and no deterioration was observed. In one place the concrete was cut away right into one of the vertical rails in the column. This was found to be in the same condition as when put in.

Cracks were observed in many of the beams under the deck in 1916, and repairs were then carried out. This was found to be necessary in the case of about one-third of the beams in the approach and in about half-a-dozen beams under the main jetty. The deck itself also required repair in half-a-dozen places. When this had been done, the whole underside of the deck and the deck beams were given a coat of ordinary gas tar. In making the repairs to the beams it was found in every case that the steel was nearer to the surface than it ought to have been. In repairing, the concrete was cut back to give sufficient room to thoroughly clean the steel, which having been done, moulds were fixed and the new concrete was rammed in place, an additional inch of cover being given.

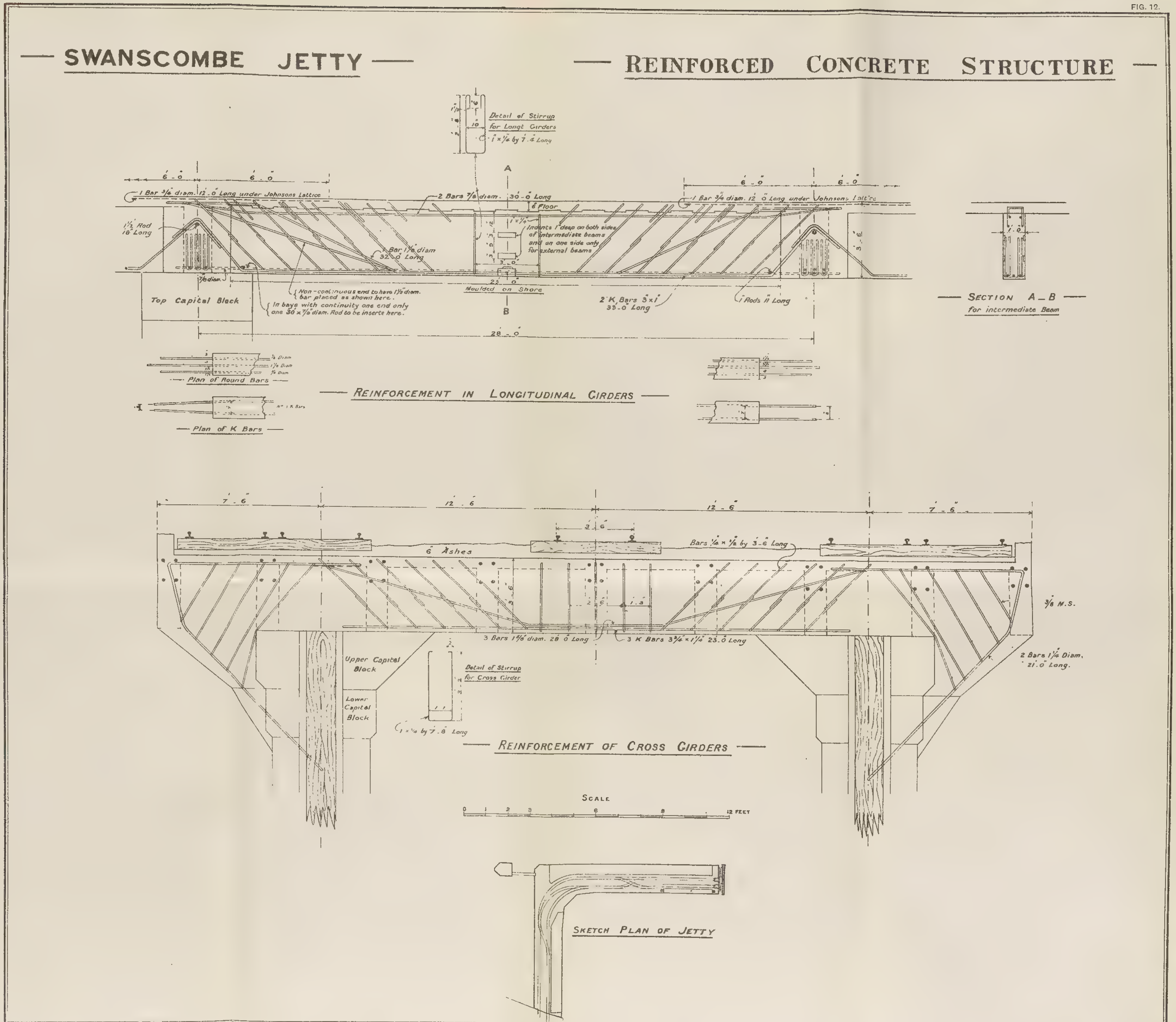
On examination of the jetty in 1917 the repaired places were all good, but about half-a-dozen other beams were found to require repair. In every one of these cases the steel was very near the surface, generally within $\frac{1}{2}$ inch. One of the effects of the tar is that it makes it very difficult to see small cracks. The appended illustration shows the reinforcement of the beams (see Fig. 12).

Thames Haven Jetty.

Description.—This structure, 136 feet long by 32 feet wide, is the head of a T jetty built in 1907 to replace an older head constructed with cast-iron screw piles, which had been damaged beyond repair by a colliding vessel. This iron head had been in use for about 25 years, and when removed the metal was, I am informed, in good condition, and some of it is being used elsewhere at the present time. The jetty is the property of the London and Thames Haven Oil Wharves, Ltd., and steamers up to 15,000 tons are accommodated.

The jetty as originally built was carried on nineteen columns 5 feet in diameter below low water, spaced about 20 feet apart. Each of these has for its support two 15 inches Considère octagonal piles, driven about 20 feet into the bed of the river. When the piles were driven, steel cylinders were lowered over them. The mud having been removed and a reinforcement of longitudinal rods and hoops having been arranged, these were concreted up to 3 feet above low-water, the 3 to 1 concrete being deposited through the water by means of a hopper tube. After the concrete was set the steel casing was removed. Above low water the columns were continued in an oval shape, 5 feet by 2 feet 6 inches, and all walings, braces, struts, etc., were constructed *in situ*, and all were

FIG. 12.


— SWANSCOMBE JETTY —
— REINFORCED CONCRETE STRUCTURE —
Detail of Stirrup for Longt Girders
1 Bar 3/4 diam. 12'-0" Long under Johnsons Lattice
2 Bars 7/8 diam. 30'-0" Long
6" Floor
1 1/2 Rod 16" Long
1 Bar 1 1/8 diam 32'-0" Long
Top Capital Block
Non-continuous end to have 1 1/8 diam. bar placed as shown here.
In bays with continuity one end only one 30' x 7/8 diam. Rod to be inserte here.
Moulded on Shore
2 K Bars 3 x 1 33'-0" Long
1 Rods 11' Long
28'-0"
Section A_B for intermediate Beam
Plan of Round Bars
Plan of K Bars
Reinforcement in Longitudinal Girders
6" Ashes
Bars 1/4 x 1/8 by 3'-6" Long
3/8 M.S.
3 Bars 1 1/8 diam. 28'-0" Long
3 K Bars 3 3/4 x 1 1/4 23'-0" Long
Upper Capital Block
Lower Capital Block
Detail of Stirrup for Cross Girder
2 Bars 1 1/4 Diam. 21'-0" Long.
Reinforcement of Cross Girders
Scale
12 Feet
Sketch Plan of Jetty

reinforced with the spiral binding of the Considère system. The deck is 6 inches thick, with an additional 1 inch layer of granolithic paving. Its maximum span is 10 feet, and it is reinforced with longitudinal rods $\frac{5}{8}$ inch diameter and transverse rods $\frac{1}{4}$ inch diameter, all at 4 inches pitch. The concrete was made from Thames ballast, washed and crushed to $\frac{3}{4}$ inch, the proportion being 1—2—4 for decking and beams, and 1—$1\frac{1}{2}$—3 for piles. The minimum cover allowed was 1 inch.

In 1912 the S.S. "Breton" collided with the jetty, doing very considerable damage. It was found on examination that the whole structure was displaced slightly, and in addition to the repairs to the superstructure, steel cylinders 6 feet in diameter were placed round each column and filled in with concrete from the river bottom to the lower bracing level, thus increasing the size of the columns from 5 feet to 6 feet diameter. These steel cylinders were left in place. To facilitate the repairs, timber dolphins were constructed at each end, projecting about 15 feet beyond the face of the jetty. Afterwards a piled timber extension was erected alongside the jetty to bring it into line with the dolphins, and also to give greater depth of water. There is about 24 feet at L.W.S.T. alongside the concrete head and about 40 feet alongside the timber extension. The repairs to the concrete work cost about £3,000.

Beyond spalling of the concrete by barges in places where it is not sufficiently fendered, no further damage by shipping has since occurred. There has been no outlay for maintenance on the concrete work.

Exposure.—The jetty is situated on the north bank of the estuary in Sea Reach, about 10 miles above Southend-on-Sea, and is subject to the alternate wetting and drying brought about by the rise and fall of the tide. The water here may be taken as normal sea-water polluted with oil.

Deterioration.—All the braces and walings in this jetty were constructed *in situ*, the reinforcement being of the Considère type of rods and spiral binding. Several of the members had been damaged and the steel exposed by the chafing of barges, but this exposed steel was not corroded to any extent. No cracks were found in the concrete from the corrosion of the steel below high water. All the lower part of the jetty was covered with seaweed, oil, and shell-fish, which would make it very difficult to detect cracks. The junctions were all good except in one case, where at the junction of a lower waling with a column half the concrete of the waling has disappeared for a couple of feet from the column, and the remainder of the waling at this local point appeared to be composed of a soft material resembling putty. In several of the columns themselves there were small holes or vacuities about low-water level, as if the concrete had been washed away before it had set. There was one brace on one side of which the spiral reinforcement could be traced by rust lines on the surface just above high-water level, and the concrete was flaking off. A few other rust spots were noticed on braces, but they had the appearance of having been sealed up. No cracks were noticed in any deck beams, and only one crack was seen in the deck itself. This ran diagonally across one of the panels.

The concrete in this jetty appeared to be softer than concrete of the

quality specified usually is, and it has been suggested that this may possibly be due to the oil with which the structure is coated. Generally, there are very few indications of any deterioration due to the corrosion of the reinforcement.

LOWESTOFT SEA DEFENCE WORKS.

By P. M. CROSTHWAITE, B.A.I., M.Inst.C.E., Secretary of the Committee.

WHILST visiting Lowestoft recently in connection with works of Sea Defence, I obtained some information with regard to timber groynes, which I think may be of interest to the Committee.

The Lowestoft sea front is cut in two by the piers of the Great Eastern Railway Company's harbour, which project beyond low-water mark. These piers, constructed partly of timber, filled in with rubble, materially affect the travel of shingle, which on this part of the coast runs from north to south. To the north of the harbour there are vast accumulations of shingle fronting extensive flats, the North Denes. Owing to the obstruction caused by the piers the travel of shingle is effectually checked, and the beach material south of the harbour entrance is mainly sand, and there is very little of this.

In 1902–4 a number of timber groynes were erected for the protection of the north and south beaches, where extensive damage had been done by inroads of the sea. On the south beach they were constructed with 10 inches by 10 inches pitch pine main piles, driven 14 feet into the beach, and 9 inches by 4 inches sheet piles driven 7 feet. On the north beach the sheet piles were 9 inches by 9 inches, driven 10 feet. The main piles, 10 feet apart, were stayed by raking struts to 10 inch by 10 inch-piles driven 8 feet from the face of the groyne. The pitch pine timber was not treated with preservatives of any kind.

The works were carried out under the sanction of the Local Government Board by means of loans amounting to £43,440, the term for the repayment of which was 10 years.

These groynes answered their purpose well, especially on the north beach, where they collected large quantities of shingle which gave ample protection to a sea wall that had been provided by the Corporation to protect the North Denes.

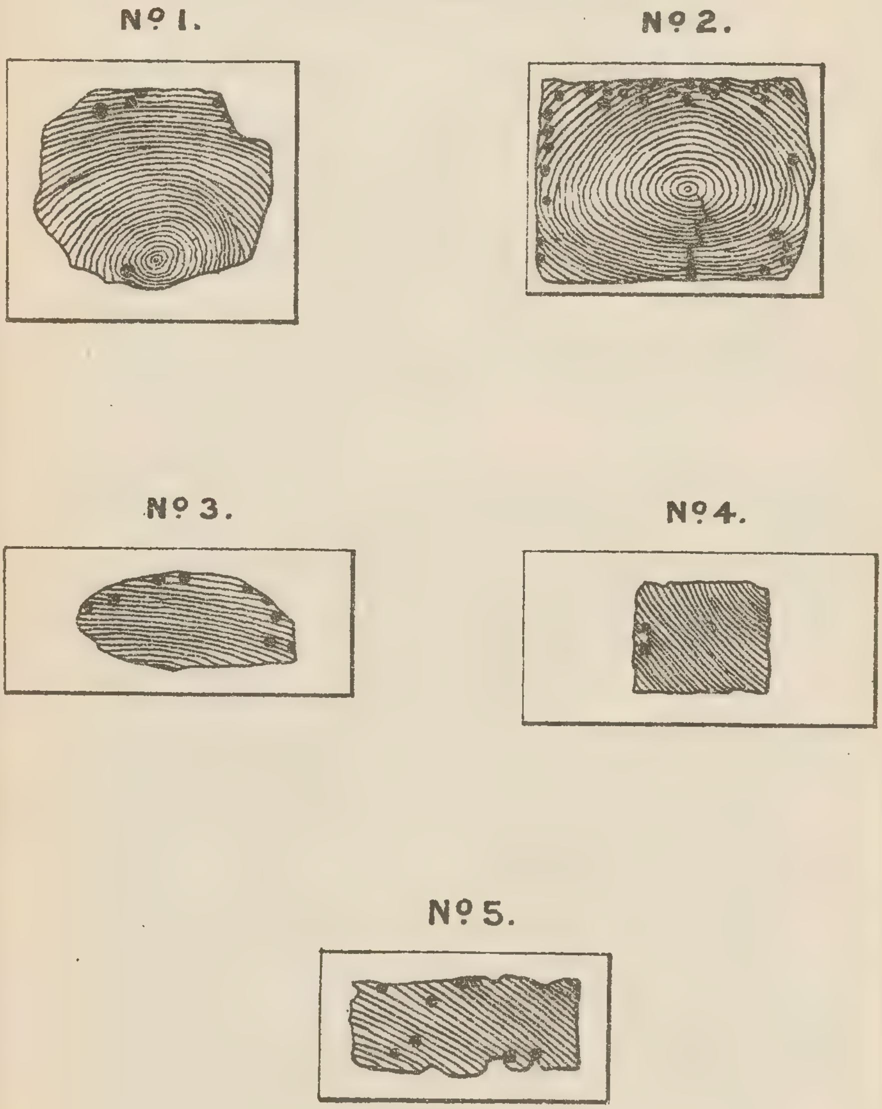
On the south beach, owing to the obstruction caused by the Great Eastern Railway Company's piers above referred to, the groynes did not prove so effective in collecting beach material, but they did to a great extent afford protection to the sea front, which had been seriously threatened.

In 1912 the groynes on the south beach showed evident signs of failure and partial reconstruction became necessary. At the time it was thought that the deterioration was mainly due to abrasion by shingle, but it was subsequently found to be chiefly caused by worm action.

In carrying out the reconstruction the main and sheet piles were renewed with timber of the same description and scantlings as the old work, but the raking struts, the short piles to which they were attached, and the upper and lower walings where sound, were re-used.

FIG. 13

LOWESTOFT GROYNES.



Sections of damaged timbers. Outlines showing original sizes.

In 1915 the Corporation undertook the reconstruction of two of the groynes on the north beach that were in the worst condition, and seven groynes on the south beach. The reconstruction of other groynes on the north beach was deferred, as it was hoped they might last till after the war. This decision was only arrived at owing to the difficulty of getting work done under war conditions, and the necessity of restricting the employment of labour to the utmost. It was, however, most unfortunate, for the condition of the groynes became rapidly worse, and during exceptionally heavy weather in March, 1916, they were severely damaged, and about 800 feet of the wall protecting the North Denes was demolished. At the same time further damage was experienced on the south beach. For the reconstruction of the groynes on the north and south beaches, and for rebuilding the wall that had been demolished on the north beach, further borrowing powers were obtained in May, 1916.

These works were put in hand at once, but owing to labour difficulties during the war they proceeded very slowly. In consequence of this unavoidable delay the wall was further breached, and where not overturned it was pushed bodily seaward. At the same time the beach was so denuded of shingle that the dilapidated groynes could not hold in position, and thus long sections of the wall were exposed to the foundations.

In July, 1917, a thorough examination of the groynes on the north and south beaches was made by the Borough Surveyor, Mr. Sydney Mobbs, who reported to the Corporation that the pitch pine put in in 1912 was absolutely destroyed, and was in as bad a condition as the work it had replaced. This rapid deterioration he attributed to the new timber having been put down in close proximity to the old timbers, to some of which it was attached. These were badly infected by worm, and it was stated that in recent years pitch pine is heavily "bled," for turpentine, whilst growing, which deteriorates and weakens the timber.

On the north beach the life of the groynes has been more satisfactory, and it was not till 1914 that they showed signs of serious deterioration. Here, however, the failure is not due to worm action but to abrasion by shingle, the corners being rounded off the piles, leaving open spaces between them. The scour through these open spaces cuts out the shingle, and so reduces the level of the beach that the piles were in places undermined.

When I made my last inspection of the works for the Local Government Board I was greatly impressed with the immunity of the pitch pine from attack by sea worm on the north beach as compared with that used to the south of the harbour entrance, and also with the much more rapid destruction of the pitch pine put in in 1912 as compared with that of 1902–4, and as I thought it might be of interest to the Committee I asked Mr. Mobbs for samples of the timbers of the different dates, which he has kindly sent me.[1] Sections are given of the damaged timber, Fig. 13. It should be noted when considering the samples that all the timber was bought under the same specification, and presumably should be of the same quality.

[1] Nos. 1, 2 and 3 in diagram exposed 13 years; Nos. 4 and 5 five years.

The rapid destruction of the pitch pine piles driven on the south beach must be capable of some explanation, and it seems to me that those put forward by Mr. Mobbs appear reasonable, and point to the undesirability of connecting new to worn-eaten timber, or of using it in close proximity thereto. The question also raised by him as to the inferiority of "bled" timher is one that seems worth investigation.

Another sugestion made by Mr. Mobbs is that the immunity of the timber on the north beach from destruction by sea worm is due to its constant bombardment by shingle, which prevented the larvæ from attaching themselves to the surface through which they must bore to gain access to the interior, and it would be of interest to know if timbers subject to shingle action in other localities are similarly immune. In this connection it should be noted that none of the piles are in deep water, so that probably all the work is within reach of the shingle.

In all cases where old piles have been drawn it has been found that the worm action never extends below the average beach level, the timber below this being invariably sound.

The timber has been attacked both by teredo and limnoria, the latter appearing to be particularly active.

NEWCASTLE.

RIVER TYNE HARBOUR WORKS.

By J. MITCHELL MONCRIEFF, C.B.E., Lt.-Col. R.E., M.Inst.C.E., and R. F. HINDMARSH, M.Inst.C.E., Chief Engineer.

NOTES in regard to certain existing structures on the River Tyne, the positions of which are shown by distinguishing numbers on the accompanying chart, see Fig. 14.

SMITH'S DOCK CO., LTD.[1]

No. 4 Dock.—Ballring Docks, North Shields (*No.* 1 *on Chart*).—This ock was constructed in 1889, and it became necessary to repair the ntrance and gates last year; for this purpose a double cofferdam had to be driven across the entrance, as a ship was undergoing heavy bottom repairs n the dock at the same time.

The concrete sill had to be entirely renewed as it was very soft and loose, a quantity of what appeared to be copper slag having been mixed with the concrete as plums. The apron also had to be renewed as the same material had been used in its construction.

The hollow quoins were of greenheart and were in excellent condition. They were left in and redressed and are now in perfect condition.

The whole of the gates were of pitch pine, and it was found necessary to renew the heel and mitre posts, the top and bottom ribs and all the outside planking.

The top and bottom ribs and the planking were renewed in pitch pine

[1] The information in regard to this Company's Docks has been compiled from notes supplied by Mr. J. W. H. Stroughair, Works Engineer to the Company.

and the heel and mitre posts and the clapping and fixed sill were renewed in greenheart.

The greenheart timber had not been touched by worm, but the pitch pine in the lower portions of the gates where exposed to the water showed signs of having been attacked by limnoria.

The iron bolts were generally in a good state of preservation.

No. 2 Dock.—High Docks, South Shields (No. 2 on Chart).—The entrance and gates of this dock were repaired last year, and for this purpose a single skin cofferdam was driven across the entrance.

The concrete sill and apron had to be entirely renewed, the old concrete, which apparently was of poor quality originally, was cracked in several places and was very loose.

The dock was about 40 years old, but the gates were only built about 16 years ago by the dock carpenters, as a temporary measure, until proper gates could be constructed. This, however, had never been done.

The heel and mitre posts were of oak and being in a good state of preservation they were redressed, with the exception of a small portion at the bottom of the mitre posts which had to be renewed, but this was due to rough usage and not to deterioration.

Structures at Tyne Dock.[1]

Reinforced Concrete (Hennebique system) (*No. 3 on Chart*).—An example of this construction exists in a jetty supporting a 30-ton crane, constructed inside the dock, in enclosed water, about the year 1908. The structure consists of a reinforced deck 7 inches thick, supported by thirty hollow 18-inch square piles driven in soft ground and braced above the normal low-water level inside the dock about 10 feet below deck level.

The front piles are faced with 4-inch elm fenders, but the structure has always been protected from jars from ships by substantial floating booms.

At the outside corners one or two of the piles have been slightly damaged, the concrete having come away from the $1\frac{1}{2}$-inch diameter steelwork bars, which had a cover of $1\frac{1}{2}$ inch of concrete, and in one case a portion of the side of a pile about 18 inches square had peeled off, while a few hair cracks show a brown discoloration in piles and braces.

On the whole, however, the structure is in a remarkably good state of preservation, the decking being free from any cracks or other indications of deterioration.

Timberwork.—A comparison may be made of timbers recently taken out in reconstruction of jetties at Tyne Dock between similar timberwork inside and outside the dock, and also between timbers which have been employed in structures of different ages.

A portion of the old river jetty (*No. 4 on Chart*), has recently been removed in connection with the new Bede Quay works. This old river jetty was constructed about 1855–1859, and consisted of creosoted Baltic

[1] The information in regard to the North-Eastern Railway Co.'s property at Tyne Dock has been supplied by Mr. W. H. Dickenson, the Company's Resident Engineer, by permission of Mr. C. F. Bengough, the Company's Chief Engineer.

timber piles with English elm fenders. The quay borders the open tidal river just below the influx of the river Don, which is highly impregnated with sewage and chemical refuse. The timbers are in such a splendid state of preservation that they are now being used in other work. There are practically no signs of worm or decay, and the creosote oozes from the heads of the piles when they are re-driven.

Inside the dock, the east decking, or south-east quay (*No.* 5 *on Chart*), constructed about 1864–65, is being re-built and the old piles are being drawn, including some which were added when the jetty was strengthened in 1910–11. This structure is in enclosed water with a rise and fall of about 5 feet at spring tides and less at neap tides. The water is replenished about high water at each tide with water of nearly the same salinity as the sea, and there is practically no sewage or fresh water running into the dock. The original piles of creosoted Baltic timber are badly wormeaten between ground level and about 2 feet below normal low-water level in the dock. The strengthening piles driven about 6 years ago are of creosoted Vancouver pine, and the limnoria in some cases has commenced its destructive effects upon a surface about the size of one's hand near the ground and near the water surface.

It may also be noted that a trace of the worm has also been discovered in an adjoining timber pond connected with the dock, on untreated timber which has been lying there for only 2 or 3 years. The water in this pond is practically free from sewage and it is in fact a portion of the dock.

The elm fenders from the river jetty, which may be taken to be original, are sound and free from worm, but the original elm fenders from the coal jetties inside the dock, which may be taken as contemporary, are badly attacked.

It should be noted that one side of the dock was originally the site of some chemical works, in which muriatic acid, etc., were manufactured, and the ground over this site is saturated with chemical refuse, but I suppose that it must be many years since the effect of this could be traced in the water inside the dock.

Tyne Improvement Commissioners' Structures.

Albert Edward Dock Gates (*No.* 6 *on Chart*).—There are four pairs of gates in this dock, two in the entrance, which is 80 feet wide, and two in the lock, which is 60 feet wide; they are of greenheart throughout and were constructed in 1884; these are in good condition, although they have been in constant use for the past 33 years and have never been removed for repairs.

These gates show no sign of having been attacked by sea worm, except that the planking and mitre posts on the inside of the inner lock gate have been attacked by limnoria.

Albert Edward Dock Entrance Wharf (*No.* 7 *on Chart.*)—This wharf is about 700 feet long and 20 feet wide, and is constructed of three rows of timber piles at about $7\frac{1}{2}$ feet centres longitudinally, the main timbers are of creosoted pitch pine, and the decking of redwood deals. It was constructed in 1884, and shows no sign of deterioration through sea worm.

Coal Shipping Staiths at Whitehall Point (*No.* 8 *on Chart*).—These consist of five staiths varying in length from 110 to 320 feet and the depth of water alongside varies from 24 to 30 feet at L.W.O.S.T., the quays or river portions of the staiths are all of creosoted pitch pine and were constructed at different dates between 1872 and 1907.

The only apparent decay has taken place at the heads of some of the piles not efficiently protected, there are no signs of deterioration due to sea worm.

Import Jetty, inside Northumberland Dock (*No.* 9 *on Chart*).—This jetty is about 430 feet long by about 50 feet wide, it was constructed between 1850 and 1860 and consists of six rows of creosoted pitch pine timber piling framed and braced together.

The water in the dock is replenished about high water at each tide with sea-water from the river when the gates are open, and there is practically no sewage or fresh water running into the dock.

A number of the piles were badly wormeaten. Extensive repairs to this jetty were carried out a few years ago, when it was found that the tops of the piles had decayed to a maximum extent of about 5 feet from the top in the heart of the piles. So far as is known these piles were untreated.

Breakwaters at Tyne Entrance (*Nos.* 10 *and* 11 *on Chart*).—These breakwaters have a total length of about 1½ miles, and are in a depth of water varying from about L.W.O.S.T. to 40 feet below this level.

Their construction was commenced in 1855 and completed about 1895, but owing to a breach made in the north pier in 1897 the outer half of the north pier had to be reconstructed; this work was completed about 1910.

The older portions of both north and south piers consist of built or concrete blocks faced principally with magnesian limestone and sandstone, with aprons of 40-ton Portland cement concrete blocks, laid around the toe of the piers to protect the rubble mounds on which the older portions of the piers are founded.

The new portion of the north pier consists of Portland cement concrete blocks faced with granite and founded on clay-shale and rock.

Lias lime, Portland cement and Roman cement have all been used in the construction of these piers. In some places the lias lime has become decomposed and expanded, thus causing trouble: in some cases the Portland cement concrete apron blocks have also become decomposed, but in no case has any decomposition taken place in the Roman cement.

The magnesian limestone and sandstone facing blocks have proved satisfactory where exposed only to the action of water. The limestone, although soft in parts, becomes hard on the exposed face, but where subject to abrasion neither this stone nor the sandstone is so satisfactory as granite.

Very little trace of the teredo is found at the entrance to the Tyne, but the limnoria is active and attacks even creosoted timbers, especially the ends of bracing and cross timbers which have been cut after creosoting.

Mr. I. C. Barling, the Resident Engineer on the reconstruction of the north pier, has stated: "The destruction of the Oregon piles supporting

the staging was very rapid, as much as 4 inches having been removed from each side of a pile in 9 years, a rate of nearly $\frac{1}{2}$ inch per annum."

Greenheart timbers have been in position for over 20 years at the Tyne Piers and have not been attacked by sea-worm.

A number of 40-ton concrete foreshore blocks were made about ten years ago with Potter's Patent Red Cement and set below low-water level in the apron around the south pier. The concrete was about 1 of cement to 6 of gravel and sand. Up to the present the blocks are in perfect condition.

On the Tyne the limnoria is found below the Northumberland and Tyne dock entrances, and it is most active near the mouth of the river, but, above the named dock entrances, timber, even if not preserved, is not attacked by sea worm, and this is attributed to the pollution of the river water owing to sewage and trade effluents discharged into the Tyne.

Palmer's Shipbuilding and Iron Co., Ltd.[1]

Wharf No. 12 *on Chart.*—This is a timber structure composed of 12 inch by 12 inch timber piles, walings, etc., of usual design. It covers a front of approximately 400 yards, and consists throughout most of its length of a staging formed of three to five rows of piles, depending on the width, with two cross and four diagonal bracings. It is built in three sections, the widths being respectively 19 yards, 11 yards and 18 yards, taking the sections from east to west.

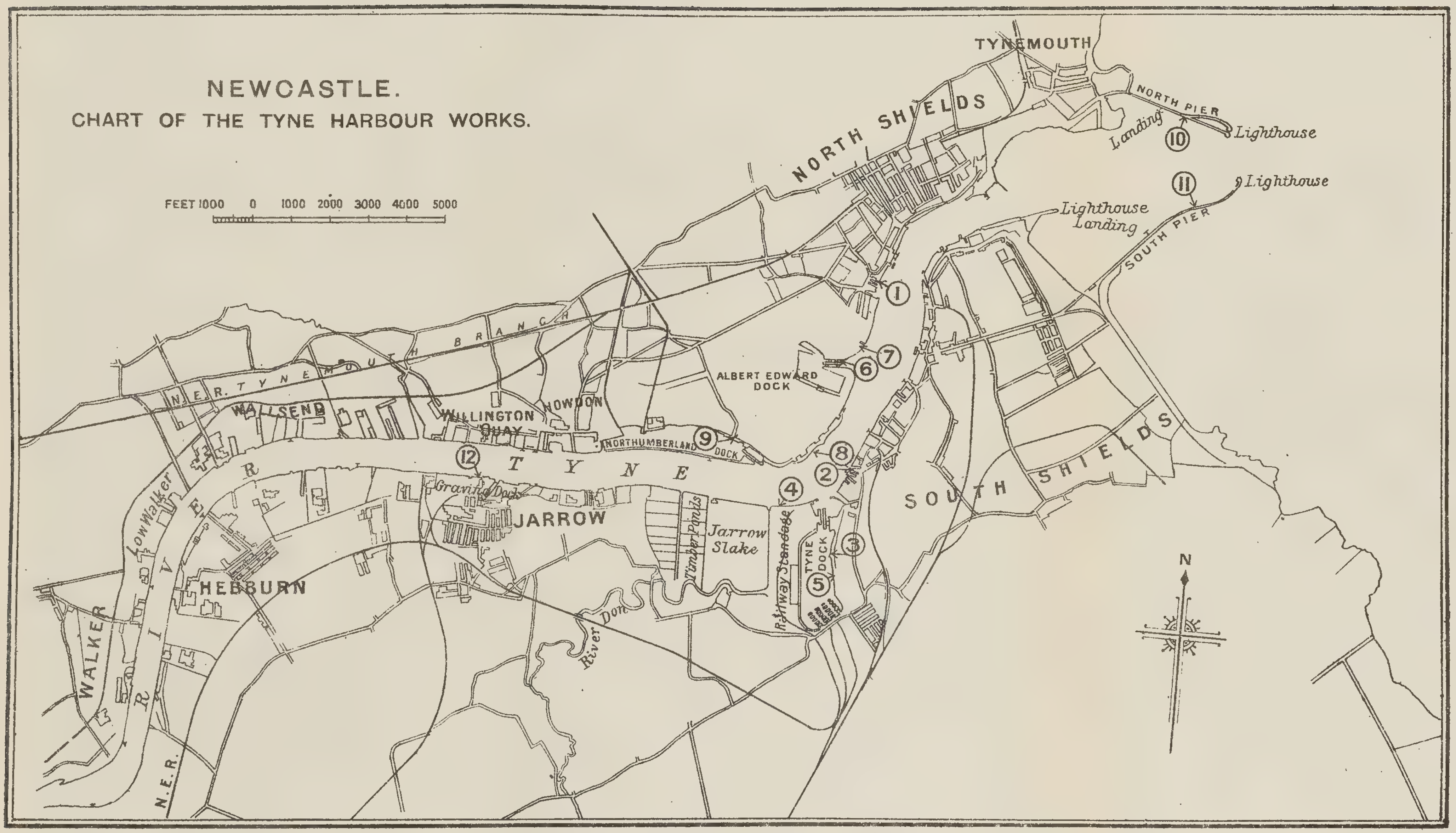
A row of sheet piling is carried along the front of the wharf. Owing to movement of the bank the sheet piling has bulged considerably towards the river. Both sheet piling and the main piles were found to be broken at the ground level. The level of the decking varies considerably, the average height being about 4 feet above H.W.O.S.T. The wharf was constructed rather more than thirty years ago.

The materials used appear to have been of good quality; piles, walings, etc., of pitch pine, and decking of red wood. There is no record concerning where the timber was obtained. It does not appear to have been preserved in any way. The materials of the wharf have deteriorated considerably in specific places, particularly above high-water mark, the decking, for instance, having rotted completely away.

Practically the whole of the piles below low-water line were found to be in an excellent state of preservation. The heads of the piles have decayed away; the appearance of the same being that due to dry rot. The timbers have also decayed away slightly above and below H.W.O.S.T. Between this level and L.W.O.S.T. the timber is found to be in better condition, the condition improving the lower it gets. Below L.W.O.S.T. the timber is in excellent condition, practically as good as when it was put in. No indication of any wormeaten timber has been discovered. The tops of the piles were badly decayed, and they do not appear to have been protected in any way.

[1] The information in regard to this Company's wharf, which is at present being taken down and rebuilt, has been furnished by Mr. Albert P. Pyne, Works Engineer to the Company.

FIG 14.


NEWCASTLE.
CHART OF THE TYNE HARBOUR WORKS.
FEET 1000 0 1000 2000 3000 4000 5000
TYNEMOUTH
NORTH SHIELDS
NORTH PIER
Landing
Lighthouse
Lighthouse
Lighthouse Landing
SOUTH PIER
ALBERT EDWARD DOCK
N.E.R. TYNEMOUTH BRANCH
WALLSEND
WILLINGTON QUAY
HOWDON
NORTHUMBERLAND DOCK
RIVER TYNE
Graving Dock
JARROW
Timber Ponds
Jarrow Slake
Railway Standage
TYNE DOCK
SOUTH SHIELDS
Low Walker
HEBBURN
WALKER
River Don
N.E.R.
N

PETERHEAD.

By W. W. HILL, M.Inst.C.E., Resident Executive Engineer.

THE Admiralty Harbour of Refuge Works, at Peterhead is an instance of the successful use of Portland cement concrete on a large scale, employed in the construction of breakwaters in deep water. The works, which are being carried out Departmentally, with the assistance of convict labour, were commenced in 1886.

The southern breakwater, 2,850 feet long, has been practically completed, and the northern breakwater is to be 1,850 feet long, 300 feet of which has been completed. There are several small subsidiary works in connection with the breakwater, also of concrete construction. On account of its exposure it is subject to the effects of storms and gales of great intensity, which owing to the length of fetch and the depth of water in the approach produce waves of greater height and force in the vicinity of the works than are known from available records at any other similar works.

The breakwaters out to low-water mark are formed of 6 to 1 cement concrete in mass, faced with granite ashlar. Beyond that distance they are composed of 6 to 1 concrete blocks, with outer granite facing; the foundations, where founded on rock, are formed of 4 to 1 concrete masswork deposited in timber frames; the upper surface of the masswork is accurately levelled to receive the blocks.

A typical cross section of the structure, where founded on rock, is appended, see inset, Fig. 15, showing the blockwork carried down to the masswork foundations in 43 feet of water. Beyond this depth, i.e., beyond 1,000 feet in length the southern arm is widened and founded on a rubble mound, the outer slope of the latter is paved with 52-ton concrete blocks joggled together.

In depositing the masswork foundations the rock bottom was carefully cleaned, and all loose rock was removed. Timber frames—built to fit the rock contour along their site—lined with jute sacking and heavily weighted were then secured in position. The mass concrete of the south breakwater, mixed by hand labour, was carefully deposited in the frames from 1½ cubic yard bottom-drop-door skips by the "Titan" until the frames were almost full. The remainder of the frame was then filled up, slightly too full with similar but finer concrete deposited in tripping bags. A heavy straight-edge was drawn along behind each deposit to level the surface. Operations were conducted as rapidly as possible so that each frame should be filled and completed in one continuous operation, whenever possible; this generally represented a full day's work.

The frames were of various lengths up to 45 feet, depending on the slope of the rock, and there were four sections in the width of the foundations. In several instances, where large gullies in the rock were met with, these masswork foundations were as much as 15 feet in depth, and they were then completed in two or three lifts. Any frame exceeding 5 feet in depth was tied together laterally with through bolts to resist distortion by the pressure of the concrete; the bolts were left in the masswork.

The superincumbent structure was formed of concrete blocks up to 50 tons in weight, set by a "Titan" travelling and revolving setting machine[1]. The blocks were built in moulds in the workyard and were generally 12 months old before they were set in the breakwater.

The concrete for the blocks was originally mixed by convict labour, but later and mainly in continuous mixers. Granite being plentiful and cheap, advantage was taken of that fact to incorporate "plums" or displacers of $1\frac{1}{2}$ to $2\frac{1}{2}$ cubic feet each in the mass up to $\frac{1}{6}$ of the whole contents of the block. The granite facing of the outer blocks was built in along with the deposit of concrete in the mould, and was bedded and jointed in 2 to 1 cement mortar and pointed with neat cement.

Several blocks were carried on together so as to give ample opportunity for working the concrete against the mould in order to form a good "skin" to the block, and also to allow each skip of concrete deposited in the mould to be properly spread and consolidated and the displacers well worked in. The upper surface of the underwater blocks was rendered and set in 2 to 1 mortar.

On several occasions it was found necessary, for a special purpose, to cut a block, and in all cases the concrete showed no signs of honeycomb or partings, but was dense, hard and exceedingly difficult to tool. The displacers and metal were fractured in the cutting or breaking of the block clean along the line of fracture, and no case was observed of displacers tearing away from the concrete; tending to show that the concrete was homogeneous, and that the method of mixing and using was satisfactory.

Samples were occasionally also quarried from the masswork foundations, and close inspection revealed an excellent quality of concrete without visible defects or porosity.

The 6 to 1 concrete blocks are composed of four parts of broken granite (machine crushed) to pass a $2\frac{1}{2}$ inches ring and two parts of sand to one of Portland cement. The 4 to 1 masswork concrete consisted of two and a half parts of broken granite to pass a $1\frac{1}{2}$-inch screen, with one and a half parts of sand, to one of Portland cement.

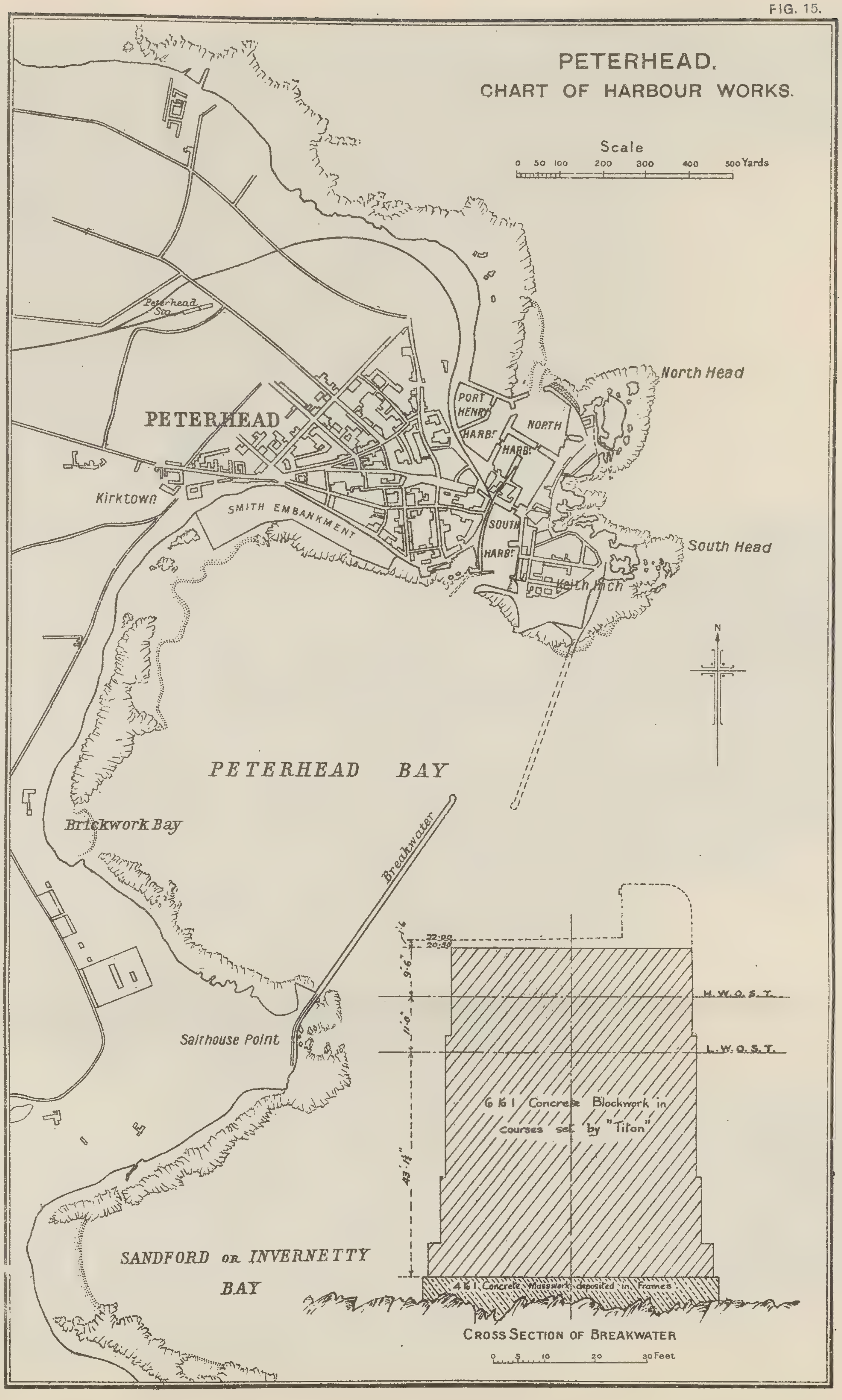
Only dense, hard freshly quarried stone was used without natural faces or weathering. It was well washed before being crushed, and the broken stone varied greatly in size (from large to small). The proportion of grit amongst the broken stone was taken into account in proportioning the sand, and also the volume of interstices in the aggregates, the variations however were not great and the crushed stone was fairly free from dust.

The sand (granitic) was obtained from foreshores in the neighbourhood, and constant attention was paid to its character, regarding coarseness, cleanliness and freedom from deleterious substances.

Fresh water was used in mixing the concrete, the consistency of the blockwork concrete being a pasty mass, without visible excess of water, capable of being easily worked with a shovel. Provision was made in the moulds for drawing off any water accumulating there during the time of

[1] See Minutes of Proceedings Inst. C.E. Vol. cxiii, p. 13.

FIG. 15.


PETERHEAD.
CHART OF HARBOUR WORKS.
Scale
0 50 100 200 300 400 500 Yards
North Head
South Head
N
PETERHEAD
Peterhead Sta.
Kirktown
PORT HENRY
HARB.
NORTH HARB.
SOUTH HARB.
SMITH EMBANKMENT
PETERHEAD BAY
Brickwork Bay
Breakwater
Salthouse Point
SANDFORD OR INVERNETTY BAY
H.W.O.S.T.
L.W.O.S.T.
6 to 1 Concrete Blockwork in courses set by "Titan"
4 to 1 Concrete Masswork deposited in Frames
43' 1½"
11' 0"
9' 6"
CROSS SECTION OF BREAKWATER
0 5 10 20 30 Feet

working and during consolidation of the mass. The masswork concrete for foundation work was deposited in a soft condition, approaching to sloppiness, to induce it to run or spread evenly when tripped but not to move too readily. When depositing the cement regard was paid to the weather, currents, etc., and little loss of cement was noticeable, the water being practically uncoloured.

Constant mixing practice by the men (who being local residents, were trained and stayed on for long periods) together with efficient supervision by careful and reliable foremen resulted in satisfactory work being produced, so far as can be ascertained, after 30 years' life of the earlier portions of the work. No signs of deterioration of the concrete have appeared in any part of the structure where it can be examined above or below water, see Chart of Harbour Works, fig. 15.

Before the introduction of the British Standard Specification for Portland cement, the character of that received on the works was exceedingly variable in regard to availability for immediate use, owing to its liability to "blow" when tested by boiling. Its condition in this respect was not indicated either by the chemical analysis or by mechanical tests carried out in conjunction with the strict specification under which it was supplied. Aeration, after arrival on the works, was therefore resorted to in all cases until the cement was shown by the boiling test to give no signs of cracking or expansion, and no cement was used in the works until this condition was attained. The whole of the masswork and about half the length of the blockwork structure of the southern arm was built with the cement of this variable character. The introduction of the Standard Specification resulted in the supply of more finely ground cement, since which time the necessity for aeration has gradually declined, and it is now only occasionally resorted to, to a small extent.

The concrete which is being used in constructing the northern arm is similar in composition to that described above for the southern arm, a batch mixer is however being used. The materials are fed into it in measured proportions and the cement is checked by weight wherever used throughout the work.

H.M. DOCKYARD, PORTSMOUTH.

By Sir THOMAS SIMS, C.B., M.Inst.C.E., Member of the Special Committee.

THE following notes are submitted, dealing briefly with local experience in regard to the effect of sea action on various works at Portsmouth. It is regretted that, owing to the present pressure of work, it has been impossible to deal more thoroughly and completely with this important subject or to make further experiments and investigations.

The works in Portsmouth Harbour which have suffered most from the effects of sea-action are the timber jetties, dolphins, and other timber structures. In these cases the woodwork is, generally speaking, attacked by boring organisms from the mud level up to a height of approximately half-tide level. In the case of structures composed of creosoted timber destruction by these organisms is most marked at the cut-ends and

halvings of braces, walings, etc., also in those crevices or angles of the structures where the borers are most protected from the sun and the drying effect of the air during low-tide periods. At such points the borers appear to have a longer time for eating into the timber and for attacking such protective coatings as may exist.

The organisms appear to effect entry at the cut-ends and halvings above referred to, as at these points portions of the timber which have remained unaffected by the creosoting process are exposed to sea-action.

From this it would appear desirable that the braces, etc., and other members of the structure should, if possible, be re-treated with creosote or other approved preservative after being cut to length, shaped and fitted, but prior to final fixing.

The timber most generally employed at Portsmouth in marine structures has been pitch pine. This timber does not, however, resist the boring organisms to any marked degree even when creosoted, as it usually is. English and American elm, where used, have been found to be a ready prey to the boring organisms, and to have a life of only 7 to 10 years in Portsmouth waters. Greenheart has been used in fenders, and is still found to be in good condition after many years of exposure to marine action.

In regard to measures taken from time to time with a view to prolonging the life of timber in marine structures, the following observations are submitted:—

Creosote.—Creosote, applied under pressure to timber, appears the most generally satisfactory treatment to ensure against attacks of boring organisms. Pitch pine, largely used in jetties, etc., at Portsmouth does not, owing to its resinous nature, take the creosote well; the creosote in many cases fails to penetrate the wood to a depth of more than $\frac{1}{2}$ inch to $\frac{3}{4}$ inch. For this reason non-resinous fir woods would probably give better results, in so far as protection against borers goes, as better impregnation by creosote would take place.

Iron Rust.—It has been observed that where the surface of the timber has been affected by iron rust, little or no deterioration owing to borers has taken place. This is noticeable under and adjacent to iron straps, bolts, etc. In order to obtain this protective effect, close scupper-nailing has been tried in some instances, and with a good measure of success. As an instance of this form of protection, a beacon pile may be mentioned. This is a single pile, 20 inches by 16 inches, apparently of Memel fir, driven into the mud, the level of which dries at about 1 foot above L.W.S.T. It is sheathed with scupper-nailing for a height of 11 feet 6 inches, above which it is unprotected. The scupper-nailed portion has recently been examined, and is apparently quite sound. The top of the pile above the nailing is now much decayed by action of the weather. The age of the pile is not exactly known, but is about 25 years at least.

Encasing with Concrete.—The lower portions of some of the piles at another place were cased in concrete. The trial has not proved quite a success, and boring organisms, which evidently have not been killed by the casing process, appear to continue to attack the wood.

Charring.—A trial on a small scale is at present in progress, with a view to ascertain whether any effective protection against boring organisms is likely to result from charring the surface of timber exposed to sea-action. With this end in view, five short lengths of fir timber (each about 3 feet by 9 inches by 6 inches) have been prepared, and were immersed in sea-water on the 24th March, 1917. These samples were marked and treated as follows:—

Marked A.	Treatment:	Charred all round.
,, B.	,,	Creosoted first and afterwards charred.
,, C.	,,	Coated with creosote after having been charred.
,, D.	,,	Untreated.
,, E.	,,	Creosoted only.

These samples were temporarily removed for inspection on the 5th November, 1917, and were afterwards reimmersed. The following conditions were then noted, viz., A, B, C, D, and E: No change. They were again removed and inspected on the 18th March, 1918, when after the usual external sea-growths had been scraped off (viz., squirters, etc.), the following conditions were noted, viz.:—

A. No decay or borers.
B. ,, ,,
C. ,, ,,
D. Borers have started to attack.
E. Slightly wormeaten at one end where creosote did not penetrate.

It is proposed to continue these observations, recording periodically the changes that occur.

In regard to sea-action on cast iron and steel in marine structures, the following notes are subjoined, viz.:—

Cast Iron (e.g. in cylindrical piles, pile-caps, etc.) does not appear to have deteriorated to any marked extent. The cast-iron piles in a jetty (erected in 1882) were examined in 1908, and the condition was reported as very good. Similarly the cast-iron piles of another jetty (erected in 1888) were also examined in 1908, and were found to be generally in as good a condition as when first erected. Cast-iron work exposed to sea-action, etc., has in the past been almost invariably treated with Angus Smith's composition.

Steelwork.—Steel rusts most rapidly where exposed alternatively to wet and dry conditions due to rise and fall of tide or where condensation is set up, e.g., in confined spaces under decks of jetties. The rusting effect in these last positions is no doubt accentuated owing to the difficulty of securing a clean surface, perfectly free from moisture, at the time of the application of the preservative coating.

Protection of Steelwork.—Good results have been obtained by the use of bitumastic enamel. This protective coating is somewhat liable to chip off, and does not appear suitable in cases where the steelwork is liable to blows from floating stages, etc. It requires, moreover, more skill in its application than ordinary paint or tar, owing to its extremely quick

drying quality. A few remarks in regard to the protection of the steel gantry stanchions in one of the docks may be of interest in this connection. This gantry was erected in 1905, and shortly after evidences appeared of rather rapid corrosion where exposed to the action of the sea. This rusting, moreover, appeared more marked in the vicinity of the stern of dock, from which some electrolytic action between the bronze propellors of ships placed in dock (but not dry-docked) was possible. In July, 1908, it was necessary to chip and coat the steelwork, tar being used on this occasion. In April, 1911, it was again found necessary to treat the steelwork, when a portion was coated with bitumastic enamel and a portion with bituminous enamel. It became evident in 1912 that these protective coatings were not likely to remain effective for any reasonable time, and it was decided therefore to encase in concrete those portions of the steel structure exposed to sea-water. This work was carried out in 1912, and has proved, so far, an effective remedy. The minimum depth of "cover" of concrete on the steel is $1\frac{3}{4}$ inch. On examination recently made (July, 1918), the concrete casing was found to remain in excellent condition, save where small chips had been knocked off by impact of floating stages, etc. The steelwork where exposed was seen to be in good condition. Steps have been taken to repair at once all defects found in the concrete casing.

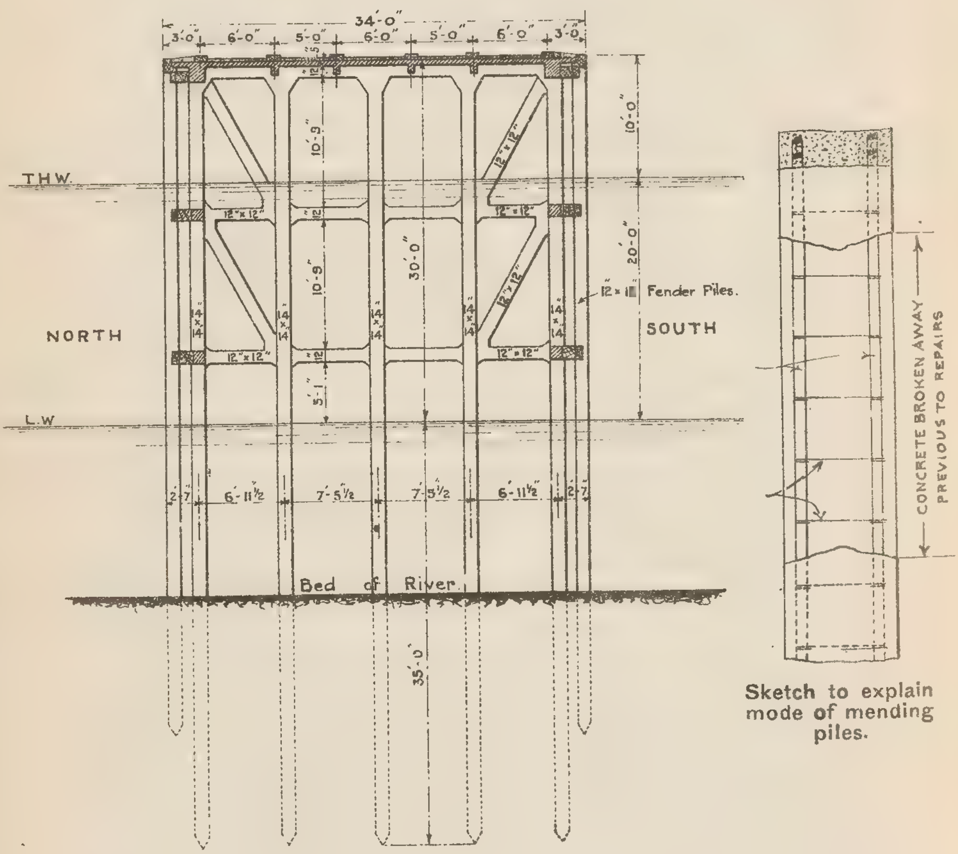
Reinforced concrete has been used to a considerable extent in recent years at Portsmouth in the construction of jetties, piers, and dolphins, in lieu of the composite wood and cast-iron cylindrical pile construction which had heretofore been in favour. The oldest work of this kind in the dockyard is a piled structure under some lines of railway on a jetty, which was carried out in 1904–5. The piles in this case were 15 inches square in section, on the Hennebique system. Other reinforced concrete works in H.M. Dockyard are a jetty constructed in 1907–8 and another jetty constructed in 1912–13. In these jetties the outer piles are 12 inches by 16 inches, the inner piles 12 inches by 12 inches, and braces 12 inches by 10 inches. The design was arranged so that no concrete in braces, walings, &c., had to be cast *in situ* lower than the level of 3 feet above L.W.S.T.

All the foregoing structures in reinforced concrete have recently been carefully examined, and are so far found to be standing well. It may be observed in this connection that the former jetty was extensively damaged by an accident in 1916 (which damage was subsequently made good). The steel reinforcement exposed owing to this accident appeared to have been entirely protected from corrosion during the 8 years of the life of the jetty at that time.

Similar conditions have been found to prevail in other reinforced concrete jetties in Portsmouth Harbour, whenever the steel reinforcement has been exposed in making good damages; such accidents are not infrequent, especially to such structures at the Submarine Depôt.

FIG. 16

Purfleet Pier.



Sketch to explain mode of mending piles.

Average Section.

PURFLEET PIER.

By C. S. MEIK, M.Inst.C.E., Member of the Special Committee.
With Notes by J. H. ANDERSON, Pier Superintendent.

Purfleet Pier, erected for the Steamship Owners Coal Association, Ltd., in 1903–1904, is situated on the north bank of the River Thames, about 17 miles below London Bridge and 7 miles above Gravesend. The pier was built of ferro-concrete on the Hennebique system, the proportion of cement to aggregates being 1 to 4 in the piles and 1 to 5 in the columns, bracings and decking above high water. A cross section of the pier is shown on the print (see Fig 16) appended.

All of the piles were driven to a set of not more than 1 inch to ten blows of a ram weighing 30 cwt., falling through 6 feet. The maximum load on a pile was intended to be 25 tons, but, owing to the increase in the weight of the machinery since the pier was designed, it is probable that the load is nearer 30 tons per pile.

In the years 1908 and 1909 cracks began to appear on the surfaces of the piles, columns and bracings, generally at or about high-water level, and these were dealt with as circumstances permitted, as will be seen from the extract from a short report sent me by the Pier Superintendent, Mr. J. H. Anderson, in February, 1914, see Appendix No. 1.

In June of this year I asked Mr. Anderson for another report on the condition of the ferro-concrete in this pier, and an extract from this I also annex, see Appendix No. 2.

I had occasion to make an inspection of the pier recently, and I then found that nearly all the inclined struts on the south side of the pier, and in the vicinity of high-water mark, were showing signs of cracking as well as a few of the vertical and horizontal ties.

There is little doubt but that these cracks owe their origin to the racking strains brought on the pier members when vessels come up against the pier in the process of being berthed alongside. When once the crack is started water or moisture gains access to the steel reinforcing bars, causing them to corrode, forcing the concrete away from the bars, and so permitting the water to get at the steel, thus accentuating the evil.

It is to be noted that by far the greater number of these cracks are in the vicinity of high-water mark of spring tides, the members lower down being, generally speaking, in a very good state.

The method employed in carrying out the repairs to the affected members are well described in Mr. Anderson's reports, supplemented by the sketch, see illustration.

Appendix No. 1.—Extract from a Report by J. H. Anderson, Pier Superintendent, dated 23rd February, 1914.

Ferro-Concrete. — In reply to your recent inquiry, the principal repairs done to ferro-concrete are situated between 6 feet 6 inches and 11 feet 6 inches from the coping of pier, this position is at or about the various high-water levels. The usual sign for these repairs is a crack running parallel with the steel bars inside, and this crack may be

anything from 6 inches to 3 feet 6 inches long, very often with no sign (externally) of corrosion. There are also several places showing rust, even to low-water mark, but not with the cracks as above mentioned.

"The method of repairing these used formerly, consisted in plastering over the cracks, or, in the case of rust marks, cutting out a small portion (probably 4-inch cube), and filling with cement plaster, but it is not the slightest use to employ the above method.

"Our present method of repair is to cut out the whole portion of the pile or beam affected, to clean thoroughly the steel and replace any defective links we may come across. Well ram in concrete ($1\frac{1}{2}$ sand to 1 cement) (no cement grout used), and in a day or two when the shuttering is taken down we give the concrete a good float over with a wooden float.

"On doing the above work during a period of between 4 and 5 years we have not had to renew any part repaired, nor have they re-cracked, and only one repaired part shows signs of corrosion, and this only slight. In the older method of repairs, practically every patch put on shows the rust coming through very shortly after repairing it.

"It is interesting to follow out these repairs, and I think the cause of the cracks is the bad design of the original links used, as it was very difficult to get them tight on the bars. We have found these slack links on every pile we have cut open and have replaced them with a new type of link. Of course, the location of these links depends on the workmen, and I regret to say they are often found out of place.

"We have tried 'ironite,' also paint over concrete for closing the pores externally. I think an elastic bitumen paint, such as 'siderosthen,' which we have used for some time on other work than concrete, would be good for ferro-concrete if applied to the work when new; on our repair work we depend a great deal on the floating over of the work."

Appendix No. 2.—Extract from a Report by J. H. Anderson, Pier Superintendent, dated 14th June, 1914.

"It may be interesting for you to know that the best results as regards repairs are obtained by making the aggregate as nearly as possible similar to the original—no cement slurry to be used—but on adding the material we thoroughly pound the same against the older concrete until we see that there is a decided adhesion to same. We do this inside a frame-piece, made so that it is used on all repairs. This frame we keep on about a couple of days, or probably less, depending on other work. When the frame is taken off we carefully float the surface of the new part with a wooden float, not using any mortar for the same, but just rubbing up the old concrete surface.

"It is of no use trying to patch up little cracks; if there is only one crack in a pile we cut into the concrete so as to examine the steel work. If this is all right, so far as location of material is concerned, I should say that this was the result of some accidental stress put on the same, therefore we should only take out about a quarter of the pile section and replace the concrete.

"On the other hand, if the steel is not in position we keep cutting out

the concrete until we find the steel all right, then throughout this length we take away the whole section of the concrete, replace defective steel, fix former steel work properly, refill with concrete, and finish off as previously stated. We find it a decided advantage to bevel slightly the ends of concrete, particularly of the upper part, making the same roughly as shewn (see sketch, Fig. 16). This will allow us to have a greater area for adhesion, and generally we give the top an extra floating before it is left to set.

"As regards tar and its effect on concrete, personally I would not use tar for ferro-concrete, but we have experimented with 'siderosthen,' which is of a tarry nature, yet free from the injurious elements of tar. We painted a small patch, but I think if the concrete is properly made, there is no need for this painting. Of course, you will remember that when we extended the pier we had all the tar material pulled up and replaced with concrete.

"At this stage it may be interesting to say that we did some of this replacement on the pier approach, but I rather think the cement was of poor quality, so much so, that even after several weeks we could rub some of the concrete to sand. We painted a portion of this with tar during the hot weather, and this has given quite good results, so far as wear is concerned, so much so that, although the tar is all worn off by the constant use of the pier-approach by our workmen, the concrete has not worn like it did before.

"With regard to the water at Purfleet, like most tidal rivers, the degree of 'saltness' is variable, and depends a great deal on the nature of the tide, weather, etc.

"During spring tides we get more sea-water here, and in seasons of heavy rain we get a lot of land water. These, I think, are the extremes, but, in addition, particularly near the shore, we get a certain amount of alluvial deposit, which has a corrosive effect on steel; this, again, is variable, and depends on winds which disturb the material, also on the traffic of the river.

"I think at times there is sufficient active material to set up electrolysis, and I suggest that it would be interesting to have a sensitive galvanometer connected, to illustrate this. I am sure that a deflection would be recorded, if connection were made to steel work, through the galvanometer to an earth plate submerged in the water, particularly at high spring tides during a dry season.

"We get a lot of troublesome repairs due to sharp corners in the ferro-concrete, these are aggravating in the sense that it is of no use patching corners, but it is essential to cut deep to get the work efficient. I think that these sharp corners should be done away with; probably an octagonal section would be better—this, of course, refers to piles—but our experience teaches us that the column system is the best, at any rate for Purfleet."

Appendix No. 3.

"The diagonal 9L was cracked on both sides for about 4 feet.

"On cutting away we found the old pattern links were nearly all

slack; some of them were $2\frac{1}{2}$ inches away from right angle, and more or less corroded. There were no links at the bottom for a length of 12 inches. We cut away 4 feet 10 inches of concrete, and replaced the 5 sets of $\frac{3}{16}$-inch links with six sets of $\frac{1}{4}$-inch links, making them tight on main bars.

"The main bars were corroded, and generally out of place in the concrete. The top was fairly good, and the bars spaced equally at 7 inches between each, although the concrete was $\frac{5}{8}$ inch thicker at one side than the other.

"At the bottom the bars were spaced from $6\frac{1}{8}$ inches up to $6\frac{3}{4}$ inches apart. This was reconcreted with 4 : 1 concrete on October 18th, 1917, i.e.:—Cement, 3; sand, 4; $\frac{3}{4}$-inch gravel, 8. Anderson's 'Ferrocrete cement' was used.

"I enclose three little prints, Plate X., showing cracks, one on diagonal and another on upright. I will, if time and the military authorities permit, take some more of these, and also take them when the concrete is cut off to show the steel work. They may be interesting for the Research Committee."

SCARBOROUGH.

By HARRY W. SMITH, Assoc.M.Inst.C.E., Borough Engineer.

Some years ago, after the sea had caused damage by blowing up a portion of the apron in front of the Royal Albert Drive, North Bay, Scarborough (which apron was constructed after the building of the wall in 1886), I observed that the mass concrete, upon which the stone setts forming the apron were laid, was of the very poorest description, and that portions of it could be broken in the hand quite easily. It presented more the appearance of lime concrete than of good cement concrete.

At first, thinking this may have been due to some faulty workmanship or to a poor lot of cement, I did not attach very great importance to it, but having occasion at a later period to execute some repairs to the same apron, on work of which I had personal knowledge during its construction, and which presented a similar appearance, I felt convinced that the matter was serious, and I therefore began to make further investigations.

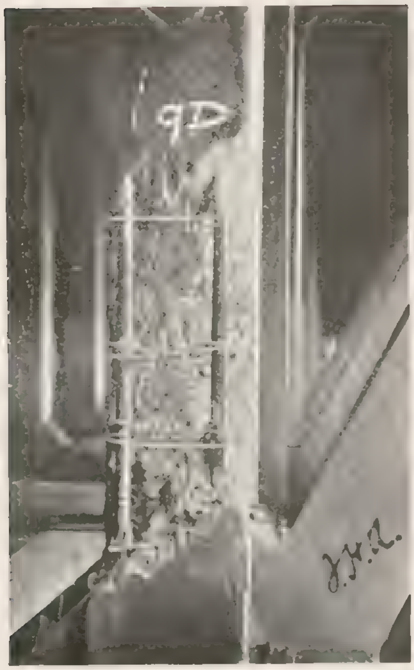
I found that the damage appeared to be particularly confined to work in connection with the Royal Albert Drive; the mass concrete, which I knew had been put in only a few years previously, exhibited signs of the same process of deterioration.

Concrete employed in the form of blocks and set above water did not appear in any way affected, and only the concrete in mass which was put in between high and low water mark showed these symptoms.

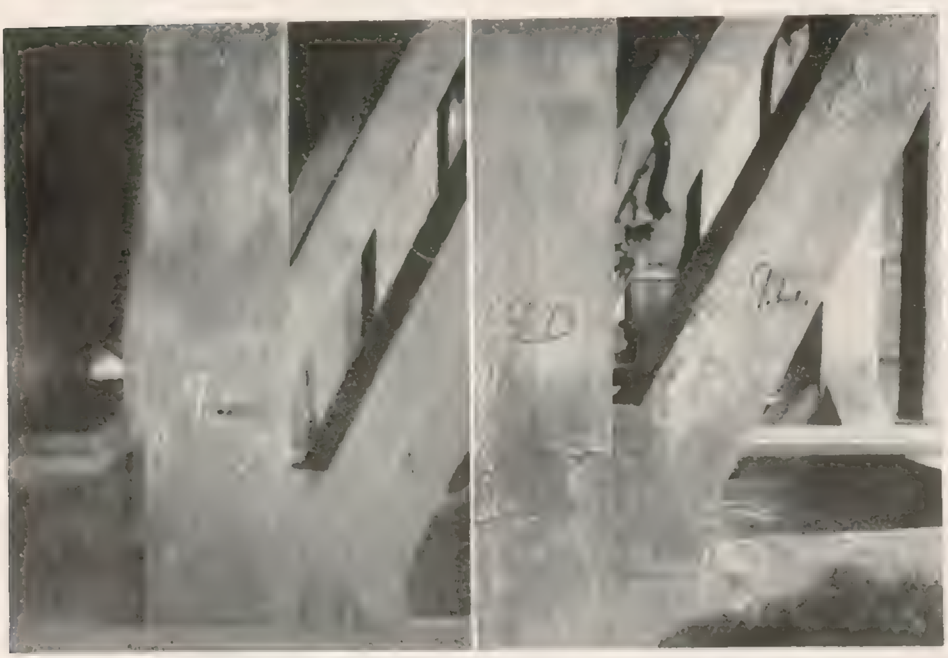
I endeavoured to find traces of similar deterioration in work which was carried out by my predecessor and myself to the north of the Royal Albert Drive, and which was between high and low water mark, but I did not meet with any.

In 1913 the Council bought the old North Pier, the seaward end of which was linked up with the Royal Albert Drive. This consisted of a stone-faced wall of similar profile to the Royal Albert Drive. Shortly

PURFLEET.



DEFECTIVE CONCRETE REMOVED TO LAY BARE REINFORCEMENT.



REINFORCED CONCRETE PILES AND BRACES SHOWING METHOD OF REPAIRING INJURIES.

after the purchase, the sea made a clean breach through this wall, and when the stone-facing was cleared away, the backing was found to consist of what appeared to be a very poor lime concrete, and a portion of it, where repairs had been made within my recollection (say about 10 years ago) by means of concrete in sacks, was in very little better condition than parts of the original wall. In this case the foreman, who executed this work for the Pier Co. and who is now in the employ of the Corporation, told me he was absolutely certain of the quality of the cement used for this repair, and he stated that it consisted of material similar to that which was used in the construction of our Marine Drive, then in progress.

In 1912 or 1913 I carried out a lot of concrete work below high-water mark in the South Bay. This comprised a large bathing-pool (the outer wall of which was in mass concrete), together with slipways and sea-walls leading up to the pleasure-grounds known as the South Cliff Gardens. At one point, within an area of less than 100 yards, I found specimens of concrete similar to, if not worse than, those in the North Bay, although the work was of such recent date; and from this I concluded that the matter was so serious as to demand further investigation. I therefore decided to abandon the use of mass concrete as far as possible for work in connection with the Royal Albert Drive. I also obtained the consent of the Council to have the matter thoroughly investigated, and Mr. Butler, of Messrs. Faija & Co., was called in for the purpose of so doing.

On receiving the report, in which Mr. Butler mainly attributes the deterioration of the cement to the water percolating from the cliff, I sought to find anywhere in the vicinity a piece of concrete which was out of reach of the sea-water, but which should show signs of similar deterioration. For some time I sought in vain, but on causing a piece of concrete retaining wall, just above the site of the old North Pier, to be cut into (there was a spring in the vicinity), I there found an exactly similar or worse state of things to prevail, although on the surface, where it was exposed to the atmosphere, the wall appeared to be as good and sound as on the day it was constructed. This, I think, shows that the conclusions with respect to the land springs arrived at by Mr. Butler in his report are sound.

I have examined portions of the backing of the original wall of the Royal Albert Drive, and, although I have found traces of damage, it is not, so far as I have been able to ascertain, in anything like so bad a condition as certain portions of the foundation of the apron immediately in front of the same, which I know to be constructed of better and stronger material so far the cement is concerned. It is possible, owing to the different circumstances—the higher sand level of the beach, and the cliff drainage being new—that this work got a chance to become properly set before coming in contact with surface water.

I am carefully watching the outer wall of the bathing pool in the South Bay, but so far see nothing amiss with it. (This wall does not come into contact with the land springs.)

The apron work in front of the Marine Drive, although it presents an appearance of slight deterioration setting in, is not anything like as bad as work in front of the Royal Albert Drive.

The geological formation of the cliffs of Scarborough is dealt with by Mr. C. Fox Strangways in his book on "The Geology of the Oolite and Cretaceous Rocks South of Scarborough," published in 1904.

Mr. B. D. Butler, who was employed to report on this case of failure of cement concrete, states that, after an investigation on the spot, he found traces of the percolation of water containing sulphates in solution. He says: "Waters containing calcium or other sulphates are a serious source of danger to cement concrete exposed to their action, and they are very liable to attack the cement, and to cause deterioration, with, in extreme cases, disintegration of the mass. . . . Having regard to the results of my investigations and analyses, I am of opinion that wherever it has had an opportunity of attacking the cement, the land water, which has been shown to be highly charged with calcium and other sulphates, is responsible for the decay and rottenness of the concrete."

SOUTHAMPTON DOCKS.

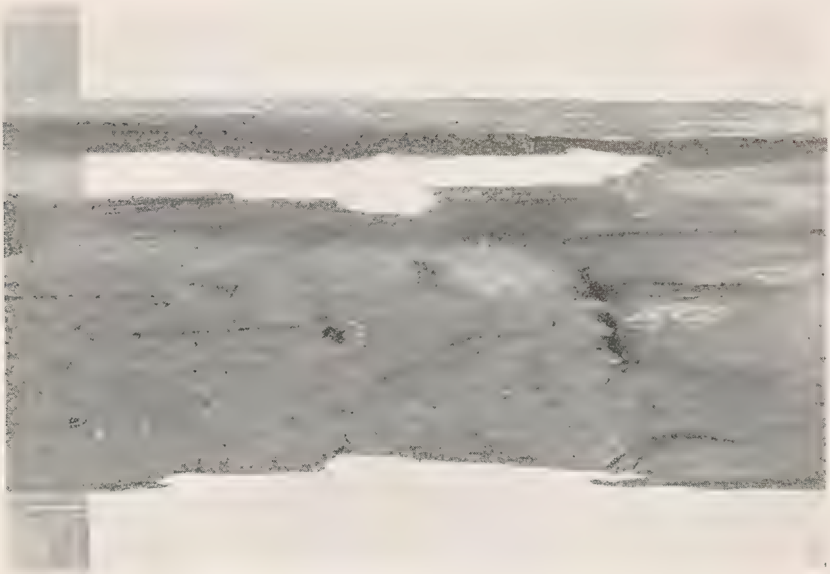
By F. E. WENTWORTH-SHEILDS, M.Inst.C.E.

Timber.—Almost every kind of timber at Southampton when standing in sea-water is attacked by marine borers. The *Teredo navalis* is rarely if ever found in this water, and the destruction is due to the *Limnoria lignorum,* which usually attack the wood in very large numbers, boring innumerable holes about $\frac{1}{30}$ inch in diameter, and causing the timber to peel off in flakes. It would seem as if it is necessary for their existence that the timber should be constantly wetted, as they do not exist above about mean-tide level nor underneath the ground surface. They seem to be most active at about low-tide level and in places where the water is frequently changed; thus their ravages have been more marked on the open river quays than in the inner dock (Fig. 17) where the water level is kept constant by a lock, and in positions like the mitre posts of gates where water is constantly leaking through, their destructive action is very great. Many kinds of timber are affected. Greenheart, as a rule, suffers but very little; oak, however, has been severely attacked, which suggests that it is not alone the hardness of a wood which will save it. Memel, pitch pine, and American elm have suffered the most heavily, see Plate XI. Tasmanian blue gum and Australian jarrah have been tried on a small scale on the river quays, and after being in the water for about 6 years these woods are attacked to a slight extent.

As regards the length of life of timber in these waters no exact figures can be given, as the attacks are very partial. A quay formed of creosoted pitch pine piles in the River Itchen (Berths 34–36) after 20 years was so eaten away as to be unsafe for traffic. Indeed, one or two piles which were untreated had to be renewed after about 15 years. Cases have been known in the River Test of untreated piles being reduced in section by 50 per cent. in 5 years, but this is exceptional.

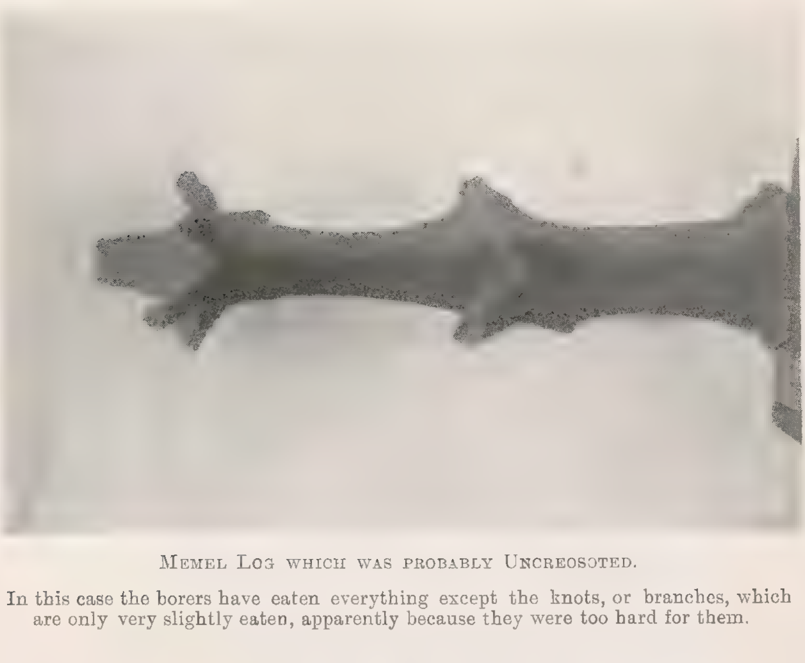
As regards methods of preserving timber, the favourite plan has been to dry the logs and then to force in creosote oil under pressure. The

SOUTHAMPTON DOCKS.



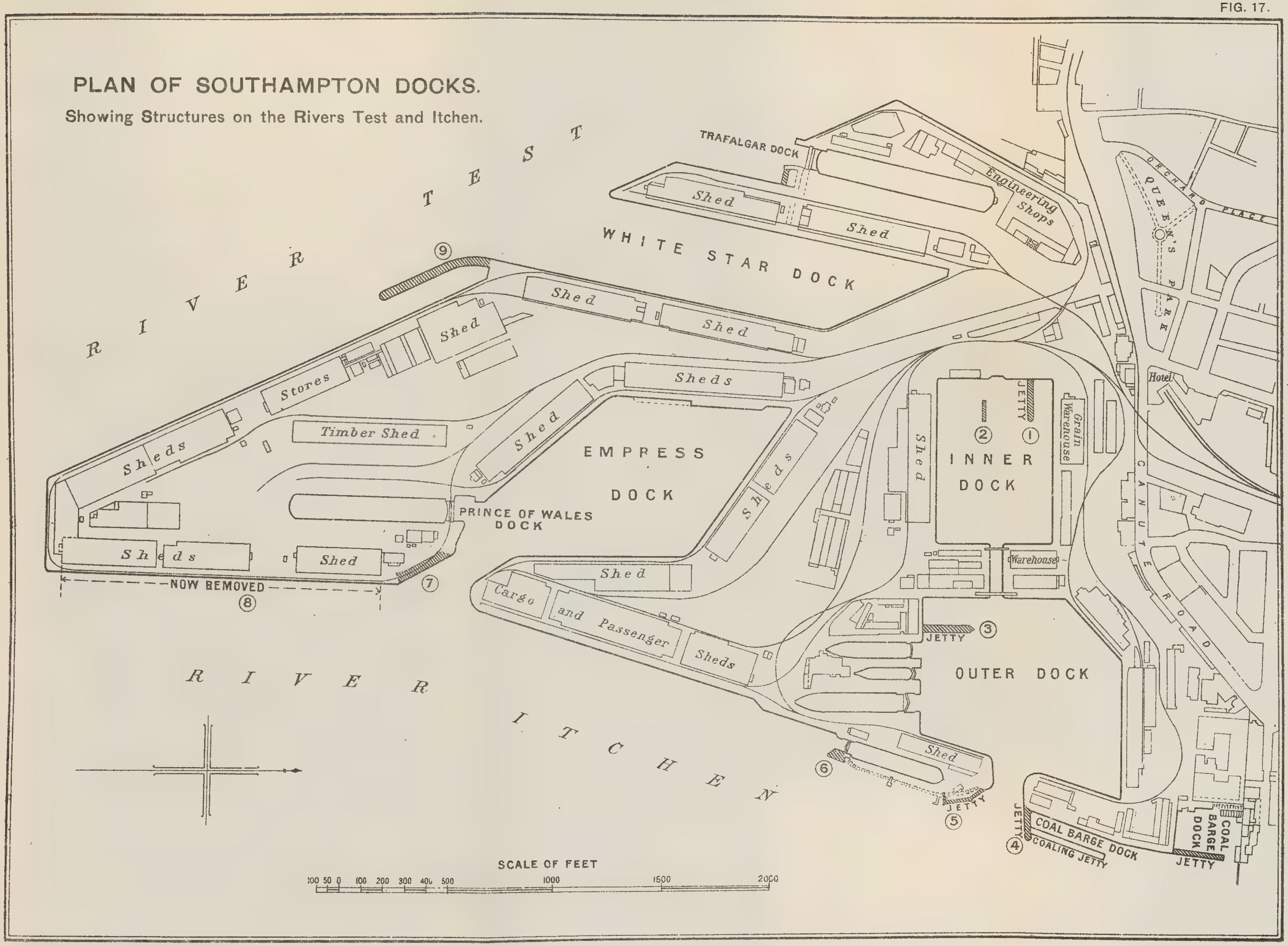
CREOSOTED MEMEL PILE.

The creosote has penetrated the sapwood at the corners, and has to some extent protected it from the ravages of the borers, who have, however, made their way through the creosoted surface and eaten the heart out of the timber.



MEMEL LOG WHICH WAS PROBABLY UNCREOSOTED.

In this case the borers have eaten everything except the knots, or branches, which are only very slightly eaten, apparently because they were too hard for them.


PLAN OF SOUTHAMPTON DOCKS.
Showing Structures on the Rivers Test and Itchen.
RIVER TEST
TRAFALGAR DOCK
Shed
Shed
Engineering Shops
WHITE STAR DOCK
Shed
Shed
Shed
Stores
Sheds
Timber Shed
Sheds
Shed
EMPRESS DOCK
PRINCE OF WALES DOCK
Sheds
Shed
Sheds
Shed
JETTY
INNER DOCK
Grain Warehouse
Warehouse
Hotel
ORCHARD PLACE
QUEEN'S PARK
CANUTE ROAD
Cargo and Passenger Sheds
Shed
JETTY
OUTER DOCK
Shed
JETTY
COAL BARGE DOCK
COALING JETTY
COAL BARGE DOCK
JETTY
JETTY
NOW REMOVED
RIVER ITCHEN
SCALE OF FEET
100 50 0 100 200 300 400 500 1000 1500 2000

result has not been very satisfactory, as the creosote penetrates little more than the sap-wood at the surface. Although this surface is fairly immune, it is not invariably so; and in places where the timber is cut across or bored or notched the creatures seem to be able to enter quite easily, and they then proceed to eat the heart out of the wood, sometimes leaving the creosoted surface untouched. Creosoted Memel timber appears to resist attack better than creosoted pitch pine, presumably because the former timber absorbs a much larger quantity of creosote oil than the latter. On one structure the piles and bracings were covered down to low-water level with flat-headed nails in order to preserve them. These, however, proved to be of little use, as the borers found their way in at the meeting-surfaces between piles and bracings, where obviously no nails could be introduced. Metal sheeting has not been tried here. We are experimenting with the carbo-teredo process of charring the surface of the timber, which seems to have been successful in Australia, but at present we have no results to offer.

The water here is fairly salt, as the rivers which flow into the estuary are very small, and it is comparatively free from sewage and chemicals, but it is very muddy.

Reinforced Concrete.—Some reinforced concrete structures at Southampton standing in sea-water have shown marked deterioration. Apparently where this occurs the water penetrates through the concrete to the steel and rusts the latter, the increased bulk of the rust then causes the concrete to crack and eventually to spall off. This action does not invariably take place. For instance, there is a reinforced jetty in the river Itchen close to the docks, which was built in 1899 and which shows no sign of deterioration. On the other hand, a jetty and quay which were built about 1902 to 1905 were seriously affected after about 7 years, and, after about 10 years, remedial measures had to be adopted. It is interesting to note that this rusting action takes place only above high-water level; below high-water neap tides, where the piles and bracings are kept constantly wetted, they are still quite unaffected, but above that level the piles, bracings, and the under side of decking have suffered considerably. The first signs of damage seem to be that rust-spots show on the face of the concrete; on cutting these out, the bars underneath are generally found to be wet and rusted, even when the concrete does not appear to be cracked. Later on, the thickness of rust increases and the cracks appear, running parallel to the line of the rod. The action is most marked in those parts of the structures where heavy rolling loads have to be supported, but it also occurs where the loads are trifling. The concrete in all cases has been made with good Portland cement and clean river gravel mixed with sand, the stones being crushed down to pass a $\frac{3}{4}$ inch ring, and the whole mixed in the proportion of 4 parts of gravel with sand to 1 of cement. The concrete is invariably sound and hard, and seems to have been quite unaffected by the action of sea-water. The cover of concrete over the rod has generally been about $1\frac{1}{2}$ inch, and rusting has occurred even with more cover than this, but to a less extent. The deterioration has been worse on the under sides of beams which have been reinforced with flat stirrups of U form; these stirrups

have often drooped a little, causing a void between the main bar and the stirrup in which wet could lodge. The damage cannot be ascribed to the driving of the piles, as the parts of the vertical members which have been affected were not driven, but built up *in situ*. Nor is it a question of 'joints,' as joints under water are unaffected, and those above are no worse than the rest of the structure.

In order to try and prevent water from getting through the pores of the concrete, as apparently it does do, a short length of one of the quays was coated with gas tar about 1910, that is about 6 years after its erection. This treatment appears to have lessened the deterioration, though it has not altogether stopped it, probably because it was applied too late. It has been found, however, that the tar adhered well, and indeed is still in good condition. It would seem as if coating the concrete with some such liquid would be a valuable preservative for structures exposed to the action of sea-water. The experience here given also suggests that the thickness of the concrete covering in marine structures should be ample, say, $2\frac{1}{2}$ inches, and that the material itself should be proportioned so as to be as non-porous as possible, also that stirrups should be secured in such a way that they cannot droop, and should be made of round iron, so as to give the maximum contact between the bar and the concrete. Again, it is desirable that the structures should be designed to be stiff as a whole, especially where heavy moving loads have to be sustained.

Mass Concrete.—No serious deterioration of mass concrete has taken place at Southampton from the action of sea-water. Many of the quay walls are built of concrete made of Portland cement and clean gravel with sand mixed in the proportion of 1 to 8; even this comparatively weak mixture has stood well. Some of the walls are 30 years old. The Trafalgar Graving Dock, which was built in 1903–5, was widened in 1912–14. The walls are of 8 to 1 concrete, and are faced with 4 to 1 mixture. During the widening the face of most of the walls was cut away, and it was found that although the sea-water had soaked constantly through some rough places in the concrete and had softened the cement a little, the action was nowhere serious, and there were no signs of the swelling and bursting of the concrete, such as has been experienced in some other ports.

SOUTHAMPTON.

By M. F. G. WILSON, M.Inst.C.E., Member of the Special Committee.

Between 1893 and 1896 the writer was resident engineer on the new dock extension works at Southampton. During that period considerable lengths of timber quays and wharfing were constructed. The timber chiefly used was pitch pine both for piles and bracing. The material was creosoted and absorbed from 4 lbs. to 5 lbs. per cubic foot. All notchings and joints in the timber were thoroughly well tarred before being put together. In one section of the work, the timber between low and high water was covered with flat headed "scupper" nails. A few years ago,

however, the whole of the work had to be renewed, the life of the timber having been about 20 years. The destruction of the materials appears to have been chiefly due to limnoria. These works were dealt with in detail by Mr. F. E. Wentworth-Sheilds, dock engineer, in the previous report.

THAMES HAVEN PIER.

By James R. ROBERTSON, M.Inst.C.E. Engineer L.T. & S. Section, Midland Railway.

Description.—Thames Haven is situated in the county of Essex on the north bank of the river Thames, about 8 miles below Gravesend and about 13 miles above the "Nore Light Ship." The river there is called "Sea Reach" and has a width, between the banks, of $1\frac{1}{2}$ mile, which is reduced to $\frac{3}{4}$-mile at low water in consequence of the large expanse of mud flats on the Kentish shore, called the Blyth sands, which is then exposed. The level of H.W.O.S.T. is 12·50 above Ordnance datum and that of L.W.O.S.T. 6·00 below Ordnance datum, or a rise and fall of the tide of 18 feet 6 inches.

Up to the year 1912 the London, Tilbury and Southend Company (the predecessors of the Midland Railway Company) had a timber pier or wharf in the river at which they carried on a considerable amount of shipping traffic. In that year the pier had to be closed for traffic because of its unsafe condition through decay, and since then it has gradually been removed, in parts at a time, until now only a comparatively small portion remains.

The pier as ultimately owned by the Tilbury Railway Company was 435 feet long, varying from 77 feet to 105 feet wide, and consisted of three portions built at three different dates. These are shown on the Plan (see Fig. 18) which accompanies this report and are thereon called Piers A, B, and C.

Pier A, built about 1854 by an independent Company under agreement with the promoters of The London, Tilbury and Southend Railway Company, is formed of open pile work with ordinary bracing and strutting, and is constructed of Dantzic timber creosoted.

Pier B, built in 1866 by a firm of traders under agreement with the London, Tilbury and Southend Railway Company and others, is formed of open pile work with ordinary bracing and strutting, and is constructed of Dantzic timber creosoted.

Pier C, built in 1889 by the London, Tilbury and Southend Railway Company, is formed of open pile work with ordinary bracing and strutting, so arranged that the two piers, A and B, were preserved and constituted parts of the whole structure, see Fig. 19. It is constructed of pitch pine uncreosoted. This was light or fine grain timber, not very resinous, and known generally as "mild pitch pine,"

In 1903 the wharf generally began to fall into decay, and this had become so marked that, in 1907, designs for repairing and strengthening it with reinforced concrete work were prepared but not carried out. In 1909 nearly all the down stream half was rendered useless through a

large steamer running into it and the rest of the wharf was closed for traffic in 1912, because of its decayed condition, see Plate XII.

Attack by Worms.—The deterioration of the piers, which eventually rendered them unfit for use, was principally due to the action of some species of sea worm which attacked the piles under water and gradually bored into and eat away the fibre of the wood.

An interesting feature about the action of the worm is that it ceases about 2·00 feet above Ordnance datum or 10 feet 6 inches below the level of H.W.O.S.T. The period during which the tide is below the level of that line is from 5 to 6 hours, and the inference to be drawn is that the exposure to the air for that length of time has some deterrent effect on the life and activities of the worm.

Creosoted Piles.—About fifty piles of Pier A, of creosoted Dantzic timber driven about 1854, were originally put down, of which twenty-two are still standing, six under the head of the old pier and sixteen under the approach gangway. These piles have nearly all been attacked and more or less consumed by the sea worm. The worm appears to get through the preservative coating of the piles, either where evaporation has taken place or at some hole or crack or bruise on the surface, and then proceeds to demolish the wood beneath the creosoted skin, rendering the pile more or less hollow. In some cases the preservative coating has partially disappeared, but the rectangular shape is generally retained and well defined. The timber appears to be eaten away in an irregular manner, but the piles are sometimes so hollow that a man's arm can be passed right through them.

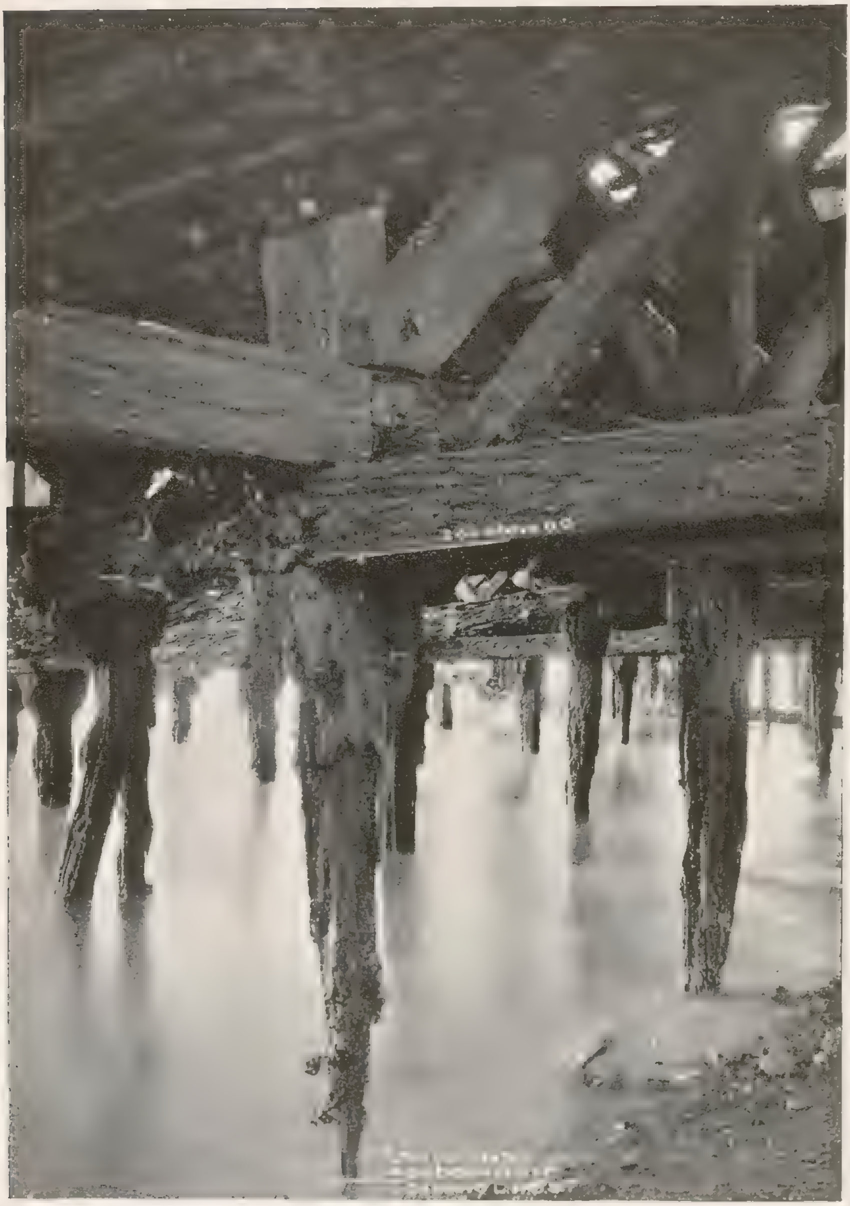
The damaged piles which are partially immersed in water are sound above the level of 2·00 A.O.D. Appearances therefore seem to indicate that the worms eat upwards from deep water as the longer the period the piles are exposed at low water the less they appear to be attacked.

Piles recently taken out of the water, on being cut through, are found to be in a good state of preservation at those parts not reached by the worm, and retain much of their original "nature." Had the worm been prevented altogether from attacking them they would now be comparatively sound and good after a life of about 60 years in the pier. The stumps of the piles drawn out are found to be quite sound below the bed of the river.

About ninety piles of Pier B, of creosoted Dantzic timber driven in 1866, were put down, of which forty-four still remain for their original full length, and are carrying the upper framing of the stage. These piles are not destroyed quite to the same extent as those at Pier A, and they appear to have been better creosoted, otherwise the observations on the state of those at A apply equally to them.

Uncreosoted Piles.—The piles of Pier C, of uncreosoted pitch pine driven in 1889, are eaten away from the outside, and are mostly demolished at a point varying from 3 feet above the river bed, where they stand at the front in deep water, to close down to the mud, where they stand at the back of the stage, and are exposed at low water. At this point they gradually assume the form of an hour-glass, the waist getting smaller and smaller until at last it snaps in two.

THAMES HAVEN PIER.



Pier "C"—General View taken in 1914 of Uncreosoted Pitch Pine Piles driven in 1889.

FIG. 18.

THAMES HAVEN PIER.

GENERAL PLAN OF PIERS A, B, C.

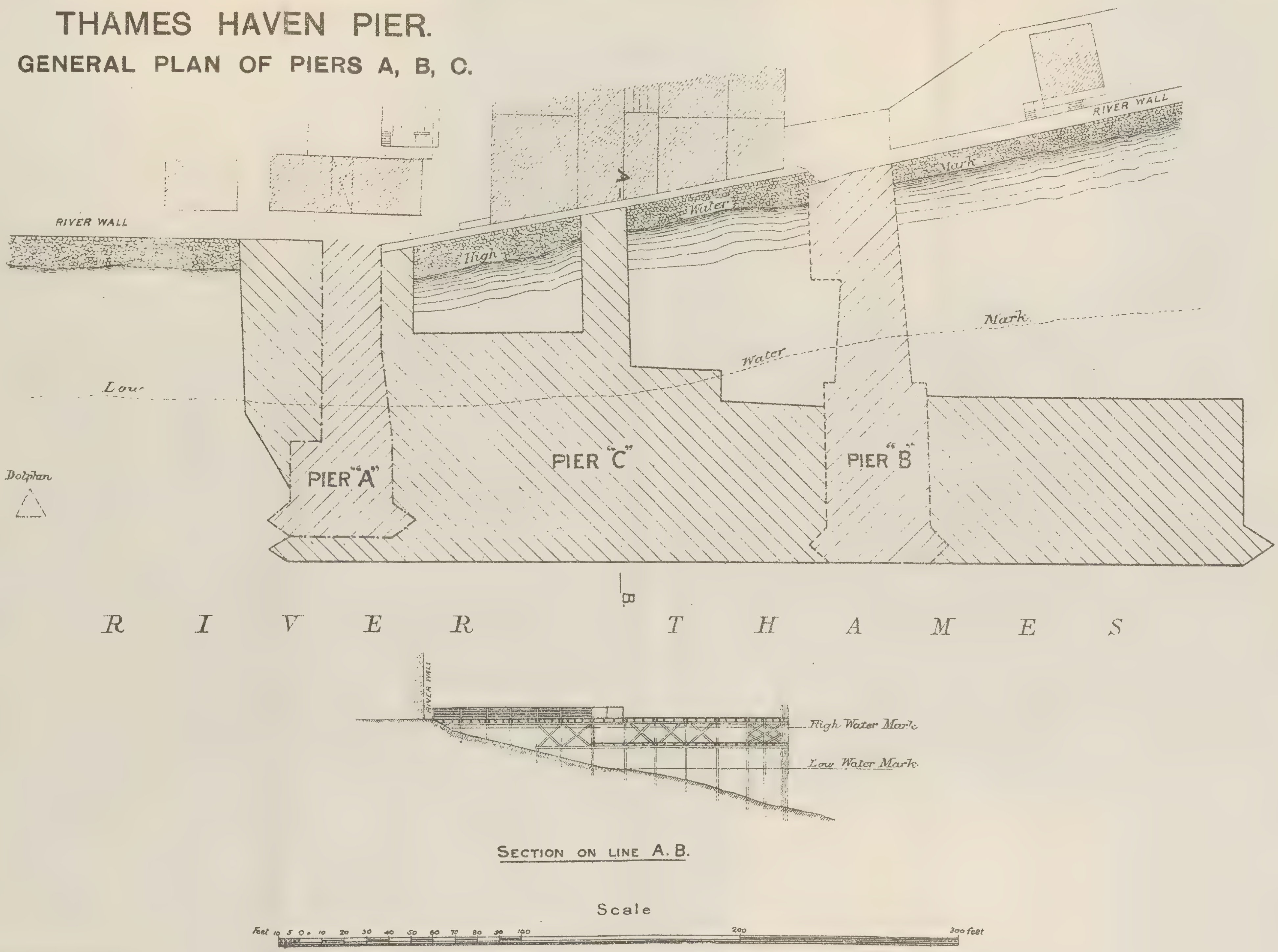
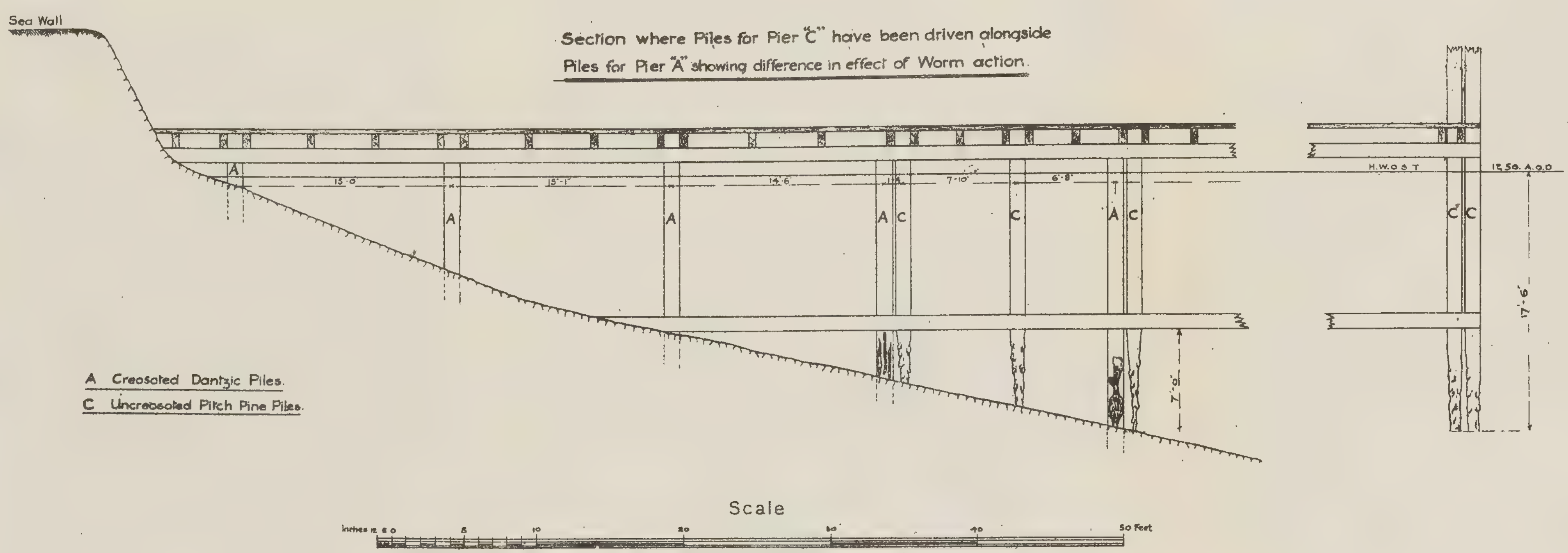


FIG. 19.

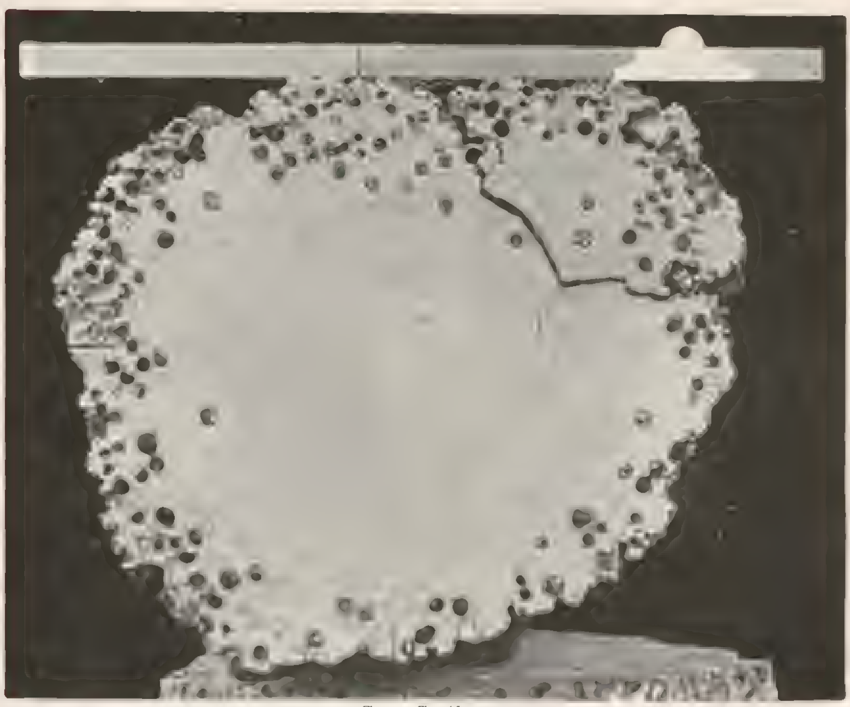
THAMES HAVEN PIER.

Section of Pier C to show position of new piling.



THAMES HAVEN PIER.

External View.



Cross Section.

Piece of Worm-eaten Uncreosoted Pile at "Waist."

On cutting through one of these piles, about 2 feet 9 inches above the waist, the timber is found to be sound from the centre outwards until the holes made by the worms are reached, see Plate XIII.

The holes are from $\frac{3}{16}$ inch to $\frac{3}{8}$ inch diameter, and are lined with a shell-like scale which becomes very brittle as it dries.

The wood is much honeycombed, proving that the worm is quite active just above the river bed, thongh its operations cease almost as soon as the clay is entered. Although honeycombed inside, the outer surface of the pile showed no worm-holes. Apparently either the worm cannot face the outside so near the mud or the scour from the current at the bottom is not sufficient to wear away the perforated timber.

A somewhat curious feature connected with the "hour-glass" shape taken by the piles is that whereas the taper is of somewhat uniform length and outline *below* the waist, it slopes gradually *above* the waist to the line 2.00 above O.D., where the full size of the pile remains, the slope, therefore, varying in appearance according to its length. Whether this peculiarity is due to the strength of the currents varying according to the depth above the river bed, and so scouring away with different degrees of rapidity the pile as it becomes honeycombed, or whether it is due to the methods of the worm, there is not sufficient data to determine.

The pitch pine in these piles, with a life of about 25 years, is not in such a good state of preservation as the Dantzic ones with a life of 60 years, and has lost some of its strength and tenacity, besides being light and brittle.

The stumps, however, of those uncreosoted piles when drawn out are found to be in sound condition below the level of the river bed, and not affected by worm action. In fact, below the river bed they are as sound as the stumps of the creosoted piles.

About 440 piles were used for this pier, of which only ninety-six now remain. Most of the latter are for the gangways from the shore, and therefore only a small or no part of them is immersed below the fatal level of 2·00 above O.D. The average life of these piles has been about 18 years.

American Elm.—This timber, in the shape of "rubbing pieces," was attached to the face of the outer line of piles, but was not driven into the river bed. It has been attacked by the worm in a similar way to the pitch pine, but appears to offer a little more resistance to the marauder.

Generally.—A discoloration in the form of a brown mark or stain is found on all piles at the level of the river bed, whether covered or exposed at low water. It is, therefore, easy to tell when a pile-stump is drawn out how far it has been driven into the clay.

GREAT YARMOUTH.

By M. F. G. WILSON, M.Inst.C.E., Member of the Special Committee.

At Great Yarmouth extensive quays for fishing craft and other vessels of comparatively light draught have been constructed, chiefly of timber, also the piers at the entrance to the river. Many of these

structures have been in use for a great number of years, and have been renewed from time to time as required. The writer's firm have frequently been consulted with regard to these matters.

The quays and wharves are built on either side of the lower portion of the River Yare, which has a considerable fresh water discharge. The rise of spring tides is about 6 feet.

Timbers used.—The principal timbers used are greenheart, jarrah, oak and creosoted Memel. The engineer to the Great Yarmouth Port and Haven Commissioners, Mr. F. G. Turner, has kindly made a recent examination of the quays, and has forwarded some notes, together with samples of timber taken from different parts of the works. These samples are forwarded herewith and are numbered—1, greenheart; 2, jarrah; 3, oak; 4, creosoted Memel, and the following notes are extracted: –

Greenheart Sample No. 1.—This sample has been badly attacked by teredo, though it will be noted the holes are not of large diameter. The length of time the timber has been in the water is not certain, but it is believed to be about 25 years. This sample appears to be somewhat exceptional, for in other greenheart piles examined but few signs of attacks were discovered.

Jarrah No. 2.—This sample, which shows considerable worm action, was taken from a pile driven 24 years ago; but here again the action is irregular, being much worse on some piles than others.

Oak No. 3.—The length of time this sample has been in the work is not definitely known, but it has been considerably attacked by teredo. In some cases the oak piling has been "scupper" nailed. Where this has been done on all four sides of the timber it appears to have been quite effective. The result of this treatment is to cause a rust incrustation on all four sides of the piles, and this forms a surface protection.

Creosoted Memel No. 4.—This sample shows worm action similar to the other specimens. When properly creosoted, the Memel appears to offer very considerable resistance to teredo. In other cases the interior of the creosoted timbers are frequently found to have been completely destroyed.

Generally speaking, at Yarmouth the life of jarrah appears to be about 25 years, and Memel, if well creosoted, about the same, greenheart and oak (especially if the latter is "scupper" nailed) being still more durable.

SPECIAL REPORTS FROM CORRESPONDING MEMBERS.

SECTION II.

COLONIAL AND FOREIGN PORTS AND HARBOURS.

The following papers have been received from the Corresponding Members with regard to Colonial and Foreign Ports, and they have been arranged in groups as shewn.

ADEN HARBOUR.

By H. BERRIDGE, M.Inst.C.E.

THE following information is at present available concerning the materials employed in this harbour.

Timber.—Benteak or Junglewood (Indian). Steps and fenders, 12 inch by 12 inch, of this timber, in tidal range, are attacked by limnoria; maximum life, 4 years, but badly gone in 2 years.

Teak (Indian) Bracings, 12 inches by 10 inches; maximum life, 5 years, but badly gone in $2\frac{1}{2}$ to 3 years. The places particularly attacked are end grain bolt holes, and surfaces in contact with piles.

Jarrah (Australian) lasts much better than above. Piles 22 feet by 12 inches by 12 inches, driven in 1911, are still serviceable. This timber seems to resist limnoria, but it is attacked by teredo. All these timbers last well for 20 to 25 years above the tidal range.

Reinforced Concrete.—Piles 12 inches by 12 inches with four $1\frac{1}{8}$ inch diameter plain reinforcement and $\frac{1}{4}$ inch diameter stirrups; rods set on an 8-inch square; the concrete covering $1\frac{1}{2}$ inches. Bought from Hennebique Co. and shipped out ready made. The piles were driven in 1907 and are still in good condition, except the upper 2 feet, where vertical cracks due to driving are found over the rods at corners.

Steel.—The life of the outer plating of an ordinary steel barge is about 4 years. Plates, $\frac{1}{4}$ inch to $\frac{3}{8}$ inch. The worst place is the water line.

Steel I beams driven as piles in 1893 are still serviceable but much corroded.

Iron (?).—Screw piles 4 inch diameter. Built 1875, taken down 1908. The piles are corroded fairly evenly, $\frac{1}{8}$ inch to $\frac{1}{4}$ inch in depth, but deep pits up to $\frac{1}{2}$ inch are occasionally found. The bracing of round rods and channel section is almost entirely gone.

I am inclined to think that some marine growths, such as oysters, which form a hard shelly coating very difficult to remove, really protect iron and steel.

Portland Cement Concrete deposited in frames, subaqueous.—(Prince of Wales Pier, 1905). The mass concrete appears sound, but slight surface disintegration seems to be going on, especially where the concrete was washed in depositing the mass.

Portland Cement Concrete in blocks 5 *feet by* 3 *feet* 6 *inches by* 3 *feet high.* —1910–1914 (Tawahi Bay, Maala Pier; Post Office Pier; Pilot Pier; Petroleum Pier). The concrete was both machine- and hand-mixed. All above water line remains quite sound and perfect.

Lime Concrete Blocks.—Mortar ground in ghani and mixed with metal by hand at Flint Island aud Club Extension in 1910–11 is fairly good, but surface disintegration is evident and some holes are showing loose metal. These defects are probably due to faulty grinding and mixing.

Lime Concrete Blocks.—The mortar ground in steam mill and machine-mixed for the Club swimming bath, 1916, is much superior to preceding. I think, however, the lime mortar is slightly soluble in sea-water. Weed

grows on machine-mixed lime blocks and on all Portland Cement blocks, but not on hand-mixed lime blocks.

Cement Concrete.—Grey volcanic vesicular stone in Portland Cement mortar, generally 4 to 1 but 1 to 1 where less than 1 hour was obtainable for setting, in tidal range.

The work generally is in first class condition, but inferior stone is in better condition in the tidal range than above it.

Oysters grow on masonry but not on concrete.

Specifications.—Cement, British Standard Specification, medium and quick ; sand coarse ; sea-water used for mixing.

The Lime is burnt from coral.

The Pumice is procured from hills on the peninsula.

Broken stone. Volcanic débris, broken to $2\frac{1}{2}$-inch gauge.

Portland Cement Concrete. Subaqueous, 1 : 2 : 4 ; Block work, 1:3:5 ; with 25 per cent. plums.

Lime Mortar.—Mixed with equal parts by vol. of lime and pumice ground together, then sand added and ground for a total of 7 minutes in steam mill.

Lime Concrete.—3 parts mortar to 5 parts metal, mixed in Ransome mixer with sufficient sea-water.

LAGOS.

By F. A. PICKLES, Assoc.M.Inst.C.E., Resident Engineer, Harbour Works.

In order that the points under observation may be properly appreciated, it appears desirable that the somewhat unusual conditions which obtain at Lagos should be set out in rather fuller detail than might be necessary were the natural conditions more normal. Lagos, which is the capital of Nigeria, and the main port for the Colony, has the only harbour between Freetown, Sierra Leone, which is distant 1,300 miles to the West, and Forcados which lies approximately 130 miles East. The harbour is situated at the mouth of an extensive series of lagoons, and the several rivers connected therewith form an unusually favourable means of inland navigation. The whole of the lagoons and rivers are for a considerable distance navigable by large canoes, and an immense amount of traffic is carried on.

In former times cargo was transhipped to small branch steamers having draughts of 6 feet light and 16 feet when fully loaded ; the ocean going steamers lying in the Roads 8 miles from the town. It was however, very seldom possible for the small steamers to cross the bar when they were drawing more than 11 feet of water, for not only was the entrance shallow, but it was rendered still more difficult for navigation by reason of the constantly shifting sand, the movements of which, after stormy weather, were extraordinary, causing frequent alterations in shoals and banks. As an illustration of this, it may be mentioned that on many occasions, as the result of one month's accretions, the foreshores were extended seaward a distance of no less than 400 feet : a few weeks later this extension had been entirely removed by erosion.

The dry and wet seasons are sharply defined. The dries, with the attendant wind known as the harmattan, last from November to March, the wet season being from April to October; the rainfall is heavy but rather variable, both month by month and annually. During the wet season enormous volumes of water are brought down by the rivers and stored in the lagoons, the discharge seaward being gradual. This fact was responsible for the continual scour which kept the harbour more or less open and the bar under some sort of control.

The ponding and relatively slow discharge of the impounded fresh water does not result in rapid admixture with the salt water, especially in the higher parts of the harbour. This fact has probably a considerable influence on teredo action which appears to be marked everywhere.

Harbour Improvements.—Reports relating to the improvements of the harbour were prepared as far back as 30 years ago by Messrs. Coode, Son & Matthews, but it was not until 1907 that the work was taken in hand seriously.

Outer Harbour Works.—The outer harbour works consisted of an eastern and western mole with a west training bank. The eastern mole was first commenced in 1908; and in 1912 it had been extended seaward a distance of 7,800 feet with the object of cutting off the large quantities of water escaping through the swashways of the bar. The outer or western mole was commenced in 1912, in order to protect the entrance to the harbour from the continual heavy swell running in from the west; at this date it has reached 4,100 feet seaward.

As soon as the eastern mole appreciably prevented the lateral escape of water, the available draught increased very rapidly and larger steamers were able to enter the harbour. It was found necessary to make more accommodation for these steamers, and further extensions were added to various wharves. Between 1907 and 1917 the official bar-draught for vessels entering the port had actually increased from 9 feet to 20 feet.

The moles are constructed of rubble granite. This is quarried 60 miles inland, and is conveyed in steel boxes over the Nigerian Railway to Apapa, which is in the upper reaches of the harbour. Owing to exceptionally heavy sea-action the western mole is protected by blocks of stone of about 12 tons in weight.

The Inner Harbour Works.—The inner harbour works are designed to be of a very extensive nature, and will involve the construction of various jetties, wharves, and docks. It is only proposed, however, to deal here with works actually completed.

The first works undertaken were the Apapa Wharf, East Mole Wharf, and West Mole Wharf, together with certain improvements and additions to the existing Customs Wharf. The jetties constructed at Apapa and at the East and West Mole were for the handling of the rubble stone required for the carrying out of the entrance works, which was carried by the Nigerian Railway to Apapa, as already mentioned, and then unloaded into steel barges and conveyed 4 miles down the harbour to the moles, at which point it was transferred in the railway conveyance boxes to trucks for final tipping into the entrance works. The jetties are of fairly similar construction, being of 6-inch wrought-iron piles, struts, and

diagonal and horizontal ties; there are bracing clips, top and bottom wales, and a fender seating; the horizontal struts are of 6-inch by 5-inch H-iron; the top wale of rolled steel joist is 18 inches by 7 inches, and the bottom wale is of built-up wrought-iron girder with $\frac{1}{2}$-inch webs and four $3\frac{1}{2}$ inches by 3 inches by $\frac{1}{2}$ inch angle irons, rivetted with $\frac{3}{4}$-inch rivets throughout.

Customs Wharf Extensions.—This work was slightly different from that already described, the piles being formed of built-up wrought-iron column sections with $\frac{3}{4}$-inch body and $\frac{7}{8}$-inch flanges and wrought-steel web plate $\frac{5}{8}$ inch thick, the shank carrying a cast-steel screw of 4 feet diameter. The piles are provided with protecting sleeves, which have already been described by Sir William Matthews in the Minutes of the Institution,[1] to protect them against corrosion near low-water level.

Further Extension to Customs Wharf.—This extension is built in reinforced concrete and was commenced 18 months ago, but it does not appear to call for any special remarks as to details of construction at the present moment.

Further Extension to Apapa Wharf.—This is an improved design on the original wharf, the piles being of a built-up type, fitted with protecting sleeves. In this case, however, owing to the difficulty of obtaining wrought iron, the piles were made of wrought steel. The deck is formed of corrugated steel plates $\frac{3}{8}$ inch thick, carrying a concrete floor.

Deterioration of Iron and Steel Structures.—In the opinion of the Consulting Engineers, Messrs. Coode, Son & Matthews, who designed these works, it was considered that iron would resist corrosion longer than steel, and much more effectively. The present condition of the structures entirely confirms the wisdom of the course adopted.

In experiments carried out in these waters, it was observed that the hard rolling skin on iron took a long time to oxidise, and before any harm could be done the protecting coating of oysters, etc., had formed. Steel does not possess this hard outer skin, and oxidises in dusty particles directly it comes into contact with salt water. When once, however, the outer skin of the wrought iron is broken through, the rust develops at a great pace bursting up the laminations, and the deterioration is much quicker than that of the steel.

The iron piles, screwed down in 1907, are in excellent preservation, the portion below L.W.O.S.T. is encrusted with a growth of oysters forming an almost complete coating of calcium carbonate. The under surface is exceedingly free from pitting or corrosion. The superstructures have been regularly scaled and coated with hot tar, and naturally therefore little deterioration is visible above low-water mark. The only portions which have suffered at all during the last ten years are the lower wrought-iron wales (which are often awash at L.W.O.S.T.) and the protecting sleeves; these sleeves, however, have been so designed that after corrosion they can be easily removed and new sleeves can be fitted in their places. It has been found that the application of either hot tar or paint to this portion of the structure with constantly wet surfaces is

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[1] Minutes of Proceedings Inst. C.E., Vol. cxcix, p. 158.

practically useless, but even here in the most vulnerable part of the structure the corrosion is very slight.

It might be mentioned here that during the rainy season the surface water in the harbour is fresh for a period of three months during the year. As the Apapa and Customs Wharves are 4 miles higher up the harbour than either of the Eastern or Western Mole Wharves, they are for several weeks longer in fresh water, but the condition of all these wharves is exactly similar.

Carter Bridge.—The steel piles of the Carter Bridge, erected by Messrs. Baker and Shelford in 1897, are in quite good condition. The piles are covered with small oysters and vegetable growth. A little corrosion is noticeable at low water on several of the piles, but it is slight considering the length of time these have been in the water. This bridge is, however, situate in the upper portion of the harbour, where there is a considerable infusion of fresh water.

Deterioration of Plant and Material.—The plant used in the construction of these works was extensive and varied, and tends to illustrate the rapidity of corrosion in this country.

Steel Rails.—The life of the rails between the eastern and western mole wharves and the moles is extremely short. The flanges of some of the rails laid five years ago have entirely corroded away.

Galvanised Iron Tubes.—The 2-inch galvanised iron pipe for water service suffered severely, various lengths towards the end of the moles have been corroded through in a period of 4 years.

Steel Stone Boxes.—Over 300 steel stone boxes of $4\frac{1}{2}$ yards capacity are used for the transportation of the stone from the quarry to the mole. Originally these were protected by coatings of hot tar, but it was found that during the extreme heat of the day blisters developed, and the corrosion behind the blisters was very rapid. In a very few months pitting to the depth of from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch took place. Boiled oil paint was found to be the most effective preservative, and this is now used entirely. The results obtained are quite satisfactory.

Steel Barges.—An excellent example of the life of steel in these waters was given by the examination of the barges. In the early days (1907–8) some of these barges of 100-ton capacity were placed in the floating dock for scraping and painting, but the dock charges were so excessive, and the work to be done was so small, that the use of the dock was discontinued. In the absence of a proper slipway, it was customary to float these barges into shallow water, and then to deal with the exposed plates. By this method, however, it was impossible to reach the keel of the barge. A suitable slipway was recently constructed and the whole of the barge fleet have been brought up for examination and repairs.

It was found that the underplates and keel were coated with a heavy growth of oysters and vegetation, and on scraping this away the plates were found to be in almost perfect condition, scarcely any pitting was noticeable, and no traces of ferric sulphide were observed. There was approximately a period of eight years between the launching of some of the barges and the examination of the keels.

Deterioration of Ferro-Concrete Structures.—The ferro-concrete addi-

tions to the Customs Wharf in the upper reaches of the harbour are too recent to give any definite information upon them. So far, however, no deterioration of any description, nor rust stains, have been noticed. Observations will, of course, be kept on this work and reference will be made to them at a later date.

Timber Structures.—The existing timber structures in this harbour are very few, and it was difficult to get really reliable information in connection with them. One timber structure was erected near the entrance to the harbour in 1911, and in this instance the piles were lengths of ekki trunk with the bark stripped. The piles varied between 8 and 15 inches in diameter. These piles were driven home into a soft, fine, loose sand, and were then surrounded by concrete held in position by cement barrels. Several of the piles have been drawn and a typical sample will now be in your possession.

In the illustration, see Fig. 20, details are given of the pile as driven, and of the same when withdrawn in September 1917. It will be noted that the top of the pile was absolutely unaffected, while the portion at the top of the concrete at H.W.O.S.T. was eaten by teredo to such an extent that it was possible to break the pile at this point quite easily. The portion driven into the ground was found to be as sound as on the day on which it was put in, but the whole of the pile between high water and bed level has been attacked under the concrete casing and gradually eaten away from the outside skin. The portion remaining was found to be perfectly sound and coated with shell, from which it would appear that the whole of the destruction of the under-water portion had not been caused by either teredo, limnoria or chelura. The broken brick concrete surrounding the pile was in very good condition.

Native Timbers—further details.—The Southern Provinces are extremely rich in timber, the varieties are many, but it is only very recently that the exploitation of these timbers has been seriously undertaken, and consequently comparatively little is known of them. It has been possible, however, to obtain reliable information in connection with a few of the better varieties, and in the circumstances a short description of these may be of interest.

A. Mahogany (*Khaya ?*).
B. Sass Wood (*Erythrophtoron guineensis*).
C. Iroko (*Chlorophora excelsa.*
D. Ekki (*Lophira procera*).

Specimens of *C* and *D* have been forwarded.

A. Mahogany.—This can be purchased in the log at Lagos at prices varying from 1*s.* 9*d.* to 2*s.* 3*d.* per cubic foot. Very large quantities are obtainable at this price. For under-water work and work subjected to rough treatment it is worthless. It is, however, being successfully used for wharf decking and for repairs to wagon frames.

B. Sass Wood.—Usual price 1*s.* 6*d.* to 1*s.* 9*d.* per cubic foot. In this class of timber the heart wood often turns out to be faulty, and logs of apparent soundness are sometimes found to be defective when cut in two: it is generally stated that only about 60 per cent. of each log will yield

useful wood. The chief use to which this timber has been put is for railway sleepers. Little information relating to its life is available, but cases are known of its being in use for a little over three years on the Nigerian Railway, and it is still sound.

C. Iroko.—This is the most useful, and was till lately one of the cheapest of the native timbers, but during the last few years the price had gradually increased: it is, however, still to be purchased at from 1*s.* 9*d.* to 2*s.* per cubic foot. This timber has probably been used more than any other in general construction work. Its length of life varies considerably, according to the conditions in which it is employed: for buildings it is admirable, but probably the chief use is as railway sleepers. Throughout the construction of these works this wood has been largely used for sleepers, wharf decking, wharf fenders and wagon repairs. It was found that the life of the sleepers in use in the quarry rarely exceeded eighteen months, while the life of the sleepers on the moles is well over five years. The quarry sleepers are for many days at a time (and specially during the wet season) under water: the rot is generally more pronounced during the dry season, and it commences invariably at the bottom edges of the sleepers; this rot does not appear to be caused by any visible insect life. The sleepers used on the moles are subjected to the action of salt water, and are alternately wet and dry. Sleepers put in 5½ years ago, except for deterioration at the dog holes, and under the flanges of the rail, are as good now as when laid.

At both the quarry and on the moles the track is identical, sleepers being laid on, and packed with, small granite rubble. Iroko would perhaps be classed as a hard wood, nevertheless it is easily worked; for timber which is subjected to extremely hard wear, and in positions in which it can easily be taken up and replaced, such as wharf fenders, decking, etc., it is indeed a suitable wood. For under-water work it is not suitable: lately an opportunity occurred for inspecting iroko logs, cut down about three years ago, and which had been floating in fresh water for six months and in salt water for a period of three months, the submerged portion of these logs was found to be eaten to a depth of 4 inches by teredo.

D. Ekki.—This is a very heavy and hard wood, denser than water. It can be purchased in logs from 2*s.* to 2*s.* 6*d.* per cubic foot. It is suitable for all classes of hard wear, and is absolutely unaffected by weather conditions. It is a common timber and the most suitable in the Colony for under-water work. It is tough, free from shakes, and easily worked.

Tests made with Ekki and Iroko Fenders.—Tests have been made at the Western Mole Wharf: the fenders for this wharf (12 inches by 12 inches by 6 feet) were placed on alternate piles and subjected to the continual rubbing of the stone barges; with the prevailing swell these timbers receive very rough treatment. In 3½ months the iroko fender was worn to a depth of 4 inches, and the ekki fender was worn to a similar depth in 7½ months. The foot of the iroko fender was almost destroyed by teredo, but the foot of the ekki fender was in rather better condition.

Rhuan Palm (Borassus flabellifer var Æthiopium).—This timber is not found here in any quantity, but it is extremely common in Sierra Leone,

[*Continued on p.* 164.]

FIG. 20.

LAGOS.

Pile of Ekki Wood with Concrete protection.

DRAWING Nº1.

Illustrating the manner in which the pile was concreted and prepared before being driven.

DRAWING Nº2.

Illustrating condition of pile when taken out of the water.

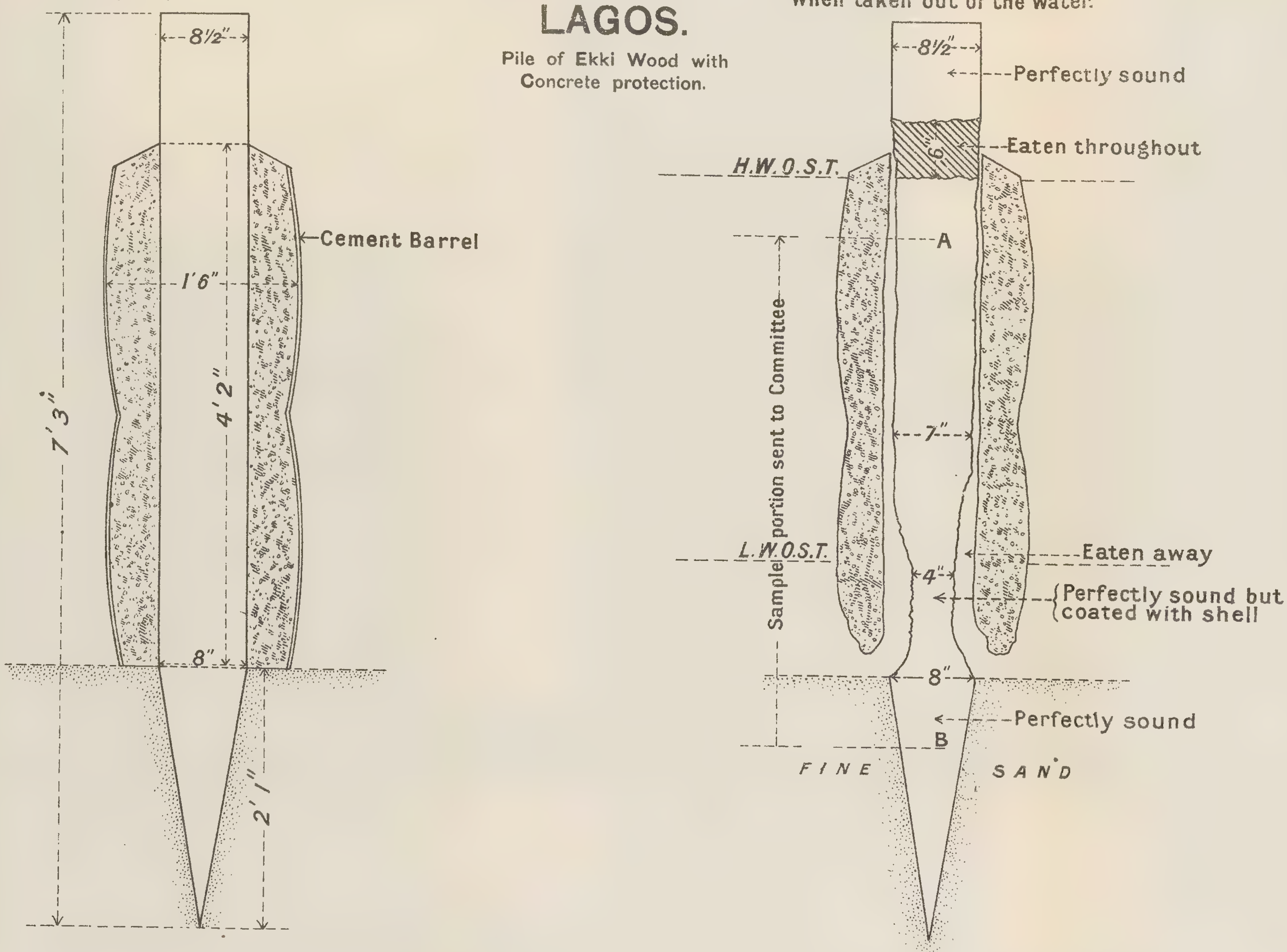


Table should follow Report by Mr. Shadwell, p. 164.]

STRUCTURES IN DURBAN HARBOUR EXPOSED TO SEA-ACTION.

Locality.	Bluff.	Bluff.	Bluff.	Point.	Point.	Congella.	Congella.
Nature of material	Timber	Steel rails	Timber	Timber	Timber	Timber (pile)	Timber (decking)
If timber, official name	Blue Gum	—	Jarrah	Blue Gum	Chilian oak	Turpentine	Blackbutt
Country of origin	Richmond	England	Australia	Richmond	—	N.S. Wales	Australia
Latitude	29·5° S.	—	—	29·5° S.	—	—	—
Longitude	29·56° E.	—	—	29·56° E.	—	—	—
Bark on or stripped	Stripped	—	Stripped	Unstripped	Stripped	Unstripped	Stripped
Hewn or sawn	Hewn pile	—	Hewn pile	Hewn	Hewn	Hewn	Sawn
Treated or untreated	Untreated	—	Untreated	Untreated	Untreated	Untreated	Untreated
Weight per cubic foot	60 lbs.	—	57½ lbs.	60 lbs.	48 lbs.	61 lbs.	52 lbs.
Date put down	1900	1901	1901	1909	1912	1907	1907
Date examined	1910	1917	1917	1911	1917	1917	1915
Attacked by	Limnoria and Teredo	Rust	Limnoria and Teredo	Limnoria and Teredo	Limnoria and Teredo, latter slight	Teredo	Rot
Position relative to mean tide level plus 3 feet	{ – 3 feet Plus 3 feet	– 3 feet Plus 3 feet	– 3 feet Plus 3 feet	Plus 1 foot	Plus 0 foot	– 3 feet	Plus 9 feet
Nature of water	Salt	Salt	Salt	Salt	Salt	Salt	—
If subject to sewage	No	Yes	Yes	No	Yes	No	No
Subject to rain-water freshet	Yes	Yes	Yes	No	No	Yes	No
Was timber surrounding sample taken	Yes	Yes	Yes	Yes	Yes	Yes	No
Seaweed adhering	No	No	No	No	No	No	No
Molluscs	No	Yes	Yes	Slight	Yes	Slightly	—
Defects noticed	Eaten to a point	Slightly corroded	Bored	Eaten to a point	Partially eaten away	Wears well	Suncracks. Rots quickly

and especially so in the Gambia. In this latter place this wood is used in the construction of practically the whole of the traders' wharves and bridges over the creeks. It has an extremely long life both in and out of water, and will probably resist the attacks of white ants longer than any other of the African timbers. It is a coarse, fibrous wood with the medullary rays filled with fine sand, and it is probably this fact which protects it against the attacks of sea organisms. It is a timber well worth investigating, and arrangements have been made for samples to be sent from the Gambia.

PORT NATAL.

By L. H. A. SHADWELL, Assoc.M.Inst.C.E., Harbour Engineer.

I AM sending you copies of a statement which I have prepared, and which I trust will be found of some service to the Committee, with regard to the first part of the investigation. [See Table on p. 163.]

The rise and fall of tide at the port of Durban (spring tides) is approximately 6 feet, and for my purpose I have taken the datum as 3 feet above low-water mark, which is shown in the Table as plus 3 feet.

Broadly speaking, turpentine timber, of which we have used considerable quantities in this harbour, is the best.

SECONDEE HARBOUR AND SIERRA LEONE,

By GEORGE HOBBS, M.Inst.C.E., Resident Engineer.

SECONDEE HARBOUR.

IN this harbour Jetty No. 1 was erected in 1899, and Jetty No. 2 in 1906. The piles in Jetty No. 1 are of iron, those in Jetty No. 2 are of steel. Some of the piles between high and low water were eaten through, owing to the cutting action of the sand. It is gathered that these were not fitted with sleeves. The pile sleeves are of wrought iron, fitted at ground level and lowered as the sand disappeared. The struts are of steel, and the rods and clips are of wrought iron, see Fig. 21.

Condition of Piles.—Rust very slight, and very little pitting. The cast iron packing blocks to pile clips are practically as new. The rivets underneath paint and growth are as good as new, the mark of the "snap" still showing in some cases. The thickness of flange measured over paint and growth is in Jetty No. 1, $1\frac{1}{2}$ inch; and in Jetty No. 2, $1\frac{3}{4}$ inch. Ditto measured on bare metal after chipping and scraping: Jetty No. 1, $1\frac{3}{8}$ inch; Jetty No. 2, $1\frac{3}{4}$ inch bare.

Condition of Sleeves.—Thickness of flange, Jetty No. 1, $\frac{3}{8}$ inch, tapering to a feather edge. A slight wear at sand level; no growth on them. Jetty No. 2., ditto, $\frac{9}{16}$ inch, no corrosion; no growth. No sign of wear, only clean at sand level.

Condition of Tie Rods.—Diameter measured outside growth on paint, Jetty No. 1, $1\frac{7}{8}$ inch; Jetty No. 2, $1\frac{3}{4}$ in. Diameter measured on bare

FIG. 21.

SECCONDEE HARBOUR WEST AFRICA.

RAILWAY JETTIES Nos. 1&2 ABOUT 300 FEET LONG.

JETTY No. 1 WAS ERECTED IN 1899.

JETTY No. 2 " " IN 1906.

CROSS SECTION

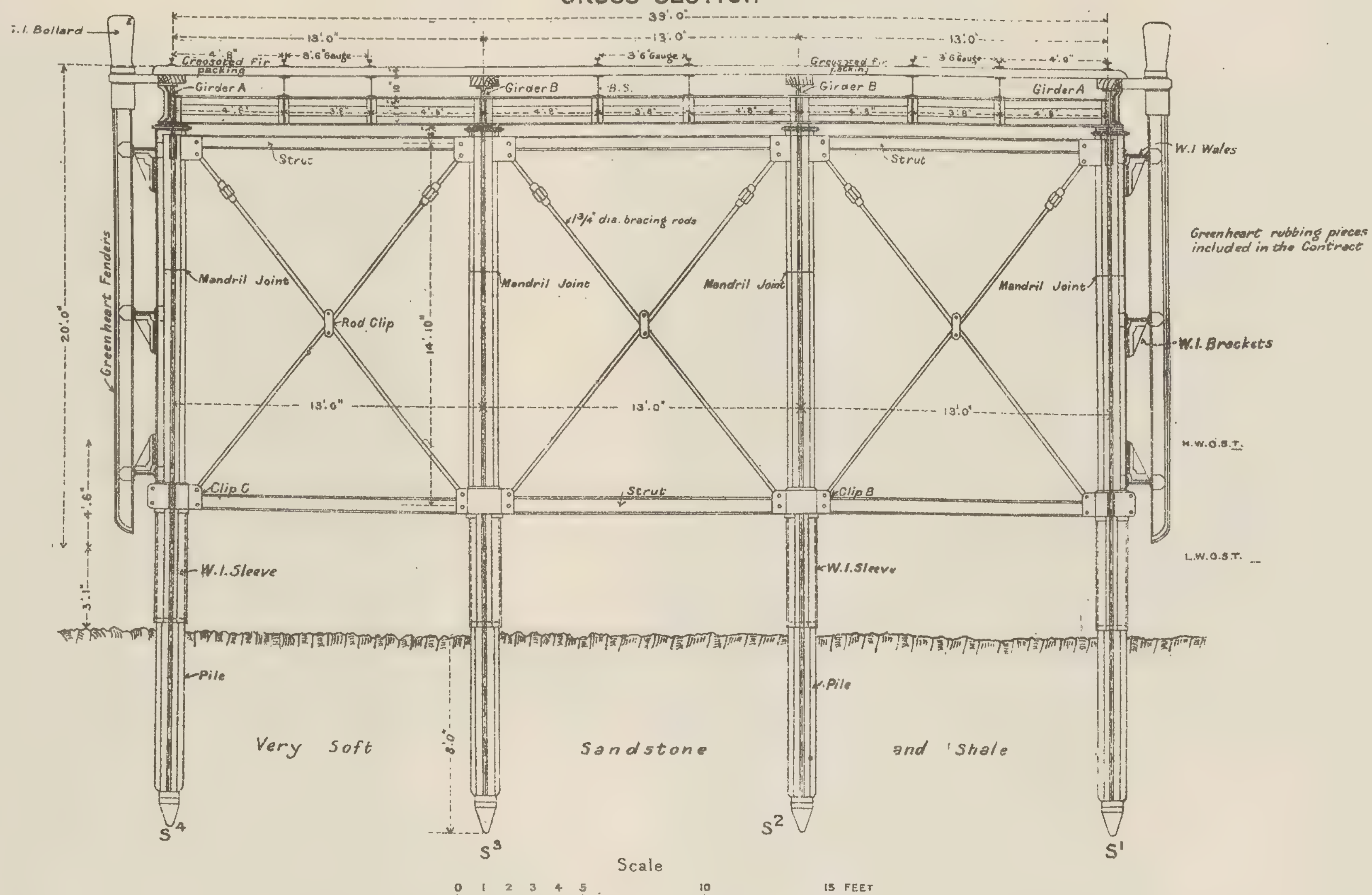
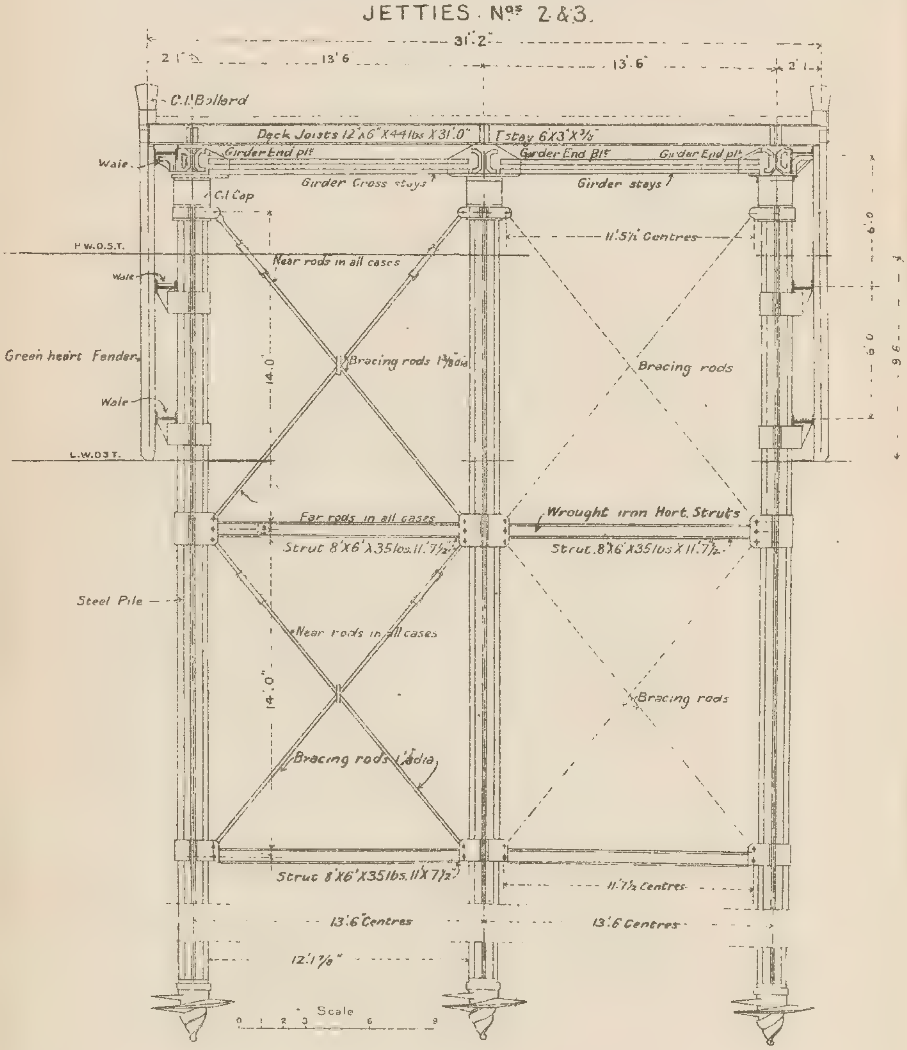


FIG. 22.

SIERRA LEONE HARBOUR. WEST AFRICA.

Cross Section of two Jetties erected at Government Wharf 1907-1908
The Jetties were about 84'.0" long and were extended in 1916-1917.

JETTIES. Nos 2 & 3.



metal after chipping and scraping: Jetty No. 1, $1\frac{1}{16}$ inch.; Jetty No. 2, $1\frac{3}{4}$ inch bare.

Corrosion on all Ironwork generally on both Jetties.—Corrosion very slight, and about the same from sand level to underside of deck. The rail bearers show some signs of corrosion, probably due to rain water dripping through the decking. Jetty No. 2 has no rail bearers. The corrosion is not more pronounced on the struts than on the tie rods. Perhaps Jetty No. 2 is in rather a better condition than No. 1, but, considering their age, there is little to choose between them.

Growth on Piles, Sleeves and Struts.—Small barnacles, not more than $\frac{1}{4}$ inch in diameter, and a sandy, spongy growth, which looks like a sponge, breaks like crusted sand, and has small worms in it. This does not extend to more than about 1 foot above L.W.O.S.T.

Pitting on all Ironwork.—Very slight and not to be measured. It anything, the pitting growth and paint below water is less than above water, but it is hardly appreciable.

Decking.—Jetty No. 1 looks like red Dantzic. It is laid athwart ships, is in good condition, and should last some years. Jetty No. 2, laid fore and aft, otherwise same as Jetty No. 1.

SIERRA LEONE HARBOUR.

Jetties Nos. 2 *and* 3.—There is no Specification of these Jetties available locally, but one can probably be obtained from Messrs. Baker and Shelford, or from the Crown Agents. Jetty No. 2 was erected in 1907, and No. 3 in 1908. The piles are of steel and the bracing rods are of wrought iron, see Fig. 22.

The rust on piles is very little, but on tie rods, from about 1 or 2 feet above L.W. downwards to ground level it is quite bad. The cake of rust, which peels off when it is hit with the hammer, is about $\frac{1}{2}$ inch thick, and exposes the bare iron, corroded in streaks or long lines, say $\frac{1}{8}$ inch deep and about $\frac{1}{8}$ inch wide.

The bottom walings are considerably corroded. The outside edges are almost feather-edged, but this is partly due to the blows from barges and boats running into them when coming alongside. The fender channels are similarly corroded, mostly at L.W., and getting less upwards till at H.W. there is nothing much the matter with them.

The growth on piles and tie rods is quite considerable from about a foot above L.W. downwards to ground level. Above, there is very little indeed. This growth is formed chiefly of large oyster shells and very large barnacles, quite $1\frac{1}{2}$ inch in diameter and 1 inch long. The barnacles only grow at about L.W. line.

There are also a lot of round patches of reddish-yellow coral about 3 inches in diameter, quite hard, and difficult to detach from the piles and tie rods.

As mentioned, the pitting on the tie rods is serious, but on the piles it is practically non-existent.

The thickness of pile clip measured over all is $1\frac{3}{16}$ inch, and the thickness of pile clip measured on bare metal is $1\frac{1}{8}$ inch.

The metal when chipped bare looks practically as good as new The

diameter of the tie rod measured over all is 2 inches, and the diameter of the rod measured on bare metal is $1\frac{3}{4}$ inch.

The original diameter was $1\frac{7}{8}$ inch. The corrosion is almost altogether confined to about L.W. line downwards, and there is nothing appreciable over say 3 or 4 feet above L.W.

The greenheart fenders are badly worm-eaten at L.W. and, say, 2 or 3 feet above.

TABLE BAY HARBOUR.

By G. T. NICHOLSON, M.Inst.C.E., Resident Engineer.

WITH regard to the information asked for in your circular letter of the 27th November, 1916, I may say that we have found concrete to be the most satisfactory material for submarine structures. As the waters of Table Bay are infested with the teredo, and also with limnoria, we carried out some time ago extensive experiments in order to ascertain the best method of protecting our timber piles from the attack of these pests, and I enclose a statement which gives particulars of these experiments.

Iron and steel work in these waters corrodes rapidly. This may be due to the high temperature and the existence of a greater quantity of oxygen in the water than is present in European waters. I am sending you several bolts which show this corrosion.

The general result of these experiments seems to point out that the best timber to resist the attacks of the teredo is a soft wood coated with some preparation of tar or similar substance which will penetrate well into the wood. Tar and other paints experimented with when applied to hard woods merely form a thin film on the surface of the wood, and do not soak into the substance of it at all; they are consequently easily rubbed off by the action of the sand, floating weed, or other matter in the water. Where this has happened with the timbers experimented with, the teredo has effected an entrance.

The creosoted log of Baltic fir (5) or other similar timber would seem to be the best pile for marine work, though in these experiments no test of the durability of either paint or tar was made.

The paints "Sotor" and "Solignum" would be without doubt good substitutes for creosote where a creosoted log had to be cut or notched for placing in a structure, or for use where timber had to be cut or fitted in small pieces in places exposed to destructive marine pests. Even the creosote does not seem efficient where the worm has the chance of maturing before penetrating the creosoted timber.

Of the specimens tested without any preservatives, those of ironwood (3) have resisted the teredo the longest, there being in the specimens only about four holes per square foot of surface. Jarrah (1) has stood fairly well, though it is attacked by the worms at the rate of from twenty to fifty holes per square foot. Karri (2) does not offer quite so much resistance, but nearly so. Pitch pine (4) is very readily attacked by the teredo, and Baltic fir (5) still more so; the specimen of Baltic deal (6) tested was eaten so as almost to drop to pieces.

RESULT OF TESTS OF VARIOUS TIMBERS AND PRESERVATIVE PAINTS EXPOSED TO SUBAQUEOUS ACTION AND PESTS AT TABLE BAY HARBOUR.

Timber.	Preservative.		Depth below L.W.O.S.T.	Remarks.
	Nature.	Application.		
(1) Jarrah . . .	None .	. . . .	40 feet	Attacked by teredo; some 20 bores per square foot.
,, . . .	None .	. . . .	44 feet	Attacked by teredo; some 50 or 60 bores per square foot.
,, . . .	None .	. . . .	20 feet	Not touched.
,, . . .	None .	. . . .	20 feet	3 or 4 bores by teredo.
,, . . .	Coal tar	1 coat, cold	20 feet	Not touched.
(2) Karri . . .	Coal tar	1 coat, cold	40 feet	Attacked by teredo in many places.
,, . . .	Sotor .	2 coats, cold	43 feet	Attacked thickly by teredo in two places where the paint had not adhered.
,, . . .	Solignum	2 coats, cold	43 feet	Attacked by teredo along an edge; 6 bores.
,, . . .	Charred	in forge fire	42 feet	Attacked by teredo in many places.
,, . . .	Sotor .	2 coats, cold	20 feet	Not touched.
,, . . .	Solignum	2 coats, cold	20 feet	1 large bore by teredo.
,, . . .	Charred	½ inch deep	20 feet	Not touched.
(3) Knysna Ironwood	None .	. . . .	40 feet	3 or 4 bores by teredo.
,, ,,	None .	. . . .	20 feet	Not touched.
(4) Pitch Pine . .	None .	. . . .	41 feet	Thoroughly riddled by teredo, though not yet quite destroyed.
,, ,, . .	None .	. . . .	20 feet	About 6 bores by teredo per square foot.
,, ,, . .	Sotor .	2 coats, cold	45 feet	Not touched.
,, ,, . .	Sotor .	2 coats, cold	20 feet	Not touched.
,, ,, . .	Solignum	2 coats, cold	43 feet	This piece was not attacked at the exposed surface by the young teredo; a few had, however, entered a piece of timber lying against this one, and had penetrated the coat of paint, after maturing, and had thus entered the pitch pine.
,, ,, . .	Solignum	2 coats, cold	20 feet	Not touched.
,, ,, . .	Creosoted	well soaked	20 feet	Not touched (from creosoted log).
(5) Baltic Fir . .	Creosoted	well soaked	40 feet	Not touched in the creosoted face by young teredo, but the teredo had attacked a piece of Baltic deal which was lying against it, and had reduced it to a spongy state, and from this some 40 holes were bored into the Baltic fir, through a creosoted face. Limnoria had also attacked this piece in a cut face.
(6) Baltic Deal . .	None .	. . . .	40 feet	Quite destroyed and reduced to a spongy state.
,, ,, . .	Coal tar	1 coat, cold	20 feet	Not touched.

The tests emphasise the fact that in Table Bay the teredo attacks the timber in greater numbers the nearer the timber is to the ground surface under water, those pieces hanging at the higher levels are attacked to a far less extent than those near the bottom; and even there a few feet would seem to make much difference, as is shown by the two specimens of jarrah (1), one in 40 feet and the other in 44 feet of water.

The test-pieces were bored and the hole was filled with coal-tar, and left to soak for a few days; they were then threaded on tie-bars in two sets, one set being hung at about 20 feet below L.W.O.S.T. and the other so as to be just clear of the ground. They were put down on the 14th October, 1904, and remained under water for 6 months (till 14th April, 1905).

A karri pile, 18 inches by 18 inches in section, which was removed from the breakwater extension staging in January, 1905, having been in place for 11 months, was found to be almost eaten away from the ground level to 3 feet above ground; up to 10 feet it was thoroughly riddled, and badly so up to about 18 feet above ground, while bores by teredo were traceable up to 38 feet above ground level, but above that level there were none. Low-water mark was at 44 feet above ground. The pile was sawn down the centre throughout its length for examination.

As an assertion had been made that at some place in Australia a jarrah pile adjacent to an electric light standard had been found quite sound after immersion for a considerable period, whilst a similar jarrah pile a short distance away was completely eaten through by the teredo during the same period, and as it was thought that the sound pile owed its immunity from the worm to electric current passing through it, due to an earth fault, the following experiments were carried out at this harbour:—

Four pieces of Oregon pine, each measuring 5 feet by 12 inches by 8 inches, were attached to the piles of a jetty 15 feet below low water. Two pieces with electrical connections were attached to one pile, and two pieces without electrical connections were attached to another pile about 18 feet away. The current was switched on and ran continuously for a period of 12 months. At the end of this time the four pieces of timber were brought up for inspection, when it was found that the pieces through which no electric current passed were not so badly attacked by the worm as the wired pieces. This leads one to imagine that the teredo is rather partial to electric shocks. However, the amount of current passing through the wired pieces was practically imperceptible.

BRISBANE.

By E. A. Cullen, M.Inst.C.E., Engineer for Harbours and Rivers.

I ENCLOSE herewith some notes on Timber used in wharves and jetties in Queensland, and concerning its durability. With regard to other materials, we have used some cast-iron pile sub-structures with wrought-iron bracing, and since 1908 we have employed reinforced concrete. It will be necessary to inspect these structures, with the particular object of this

inquiry in view, before reporting, and I will endeavour to do so at the earliest opportunity. In relation to experimental work I contemplate fixing some slabs of concrete of various strengths, with varying depths of cover, over the steel and reporting on the same. It seems to the writer that in this material an all-important matter is to determine what mixture and what thickness over the steel is necessary to protect the latter from corrosion.

Queensland Hardwoods.—Since 1860 the whole of the wharves, jetties, and so on, in Queensland ports, extending from Thursday Island in latitude 10° 35 S. to Southport in latitude 27° 57 S., have, with but few exceptions, been built of timber. The structures range from landings for small craft to wharves accommodating ocean steamers up to vessels of the Orient line type of 12,000 tons. Where the structures are situated in rivers, the waters in which they stand are, at greater or less intervals, fresh under the action of floods or freshets, but periods of 12 months or more may occur without a fresh. After a freshet the waters soon become salt again. In the Brisbane river, where the greater number of the wharves are situated, there has been but one freshet since 1898; this occurred in 1908. The normal fresh-water discharge in all the costal rivers is negligeable in quantity as affecting marine growths in the lower parts.

No noticeable pollution of the waters has occurred, and in many instances the small population and the absence of any cause of contamination precludes any possibility of pollution.

Notwithstanding the range of latitude and temperature and the varieties of timber used in the construction of the numerous structures, there are few that have escaped total destruction through the attacks of the teredo or of limnoria, and to the best of my observation, extending over 25 years, none that have escaped partial damage from that source. The timber used in these structures, which are all carried on driven piles, and the larger ones braced above L.W.S.T. has been for piles:—

Ironbark (*Eucalyptus siderophloia* and *E. crebra*)
Turpentine (*Syncarpia laurifolia*)
Swamp mahogany (*Eucalyptus regnans*)
Titree (*Melaleuca genistifolia*)
Cypress pine (*Callitris robusta*),

and for superstructure any of the hardwoods, but in the more important structures ironbark, spotted (*E. macrilata*), grey (*E. paniculata*) or blue gum (*E. tereticornis*), and tallow wood (*E. microcorys*) is usually specified.

Ironbark, used for piles, is invariably sheathed with Muntz metal sheets, usually 22 ounces per square foot, fastened over brown paper and Stockholm tar, or else over Stockholm felt with Muntz metal nails. This timber whilst protected will last indefinitely in sea-water, or at least up to 40 or 50 years, but may suffer a little at the head when old, under the headstocks, if cracks occur and moisture and dirt enter. Up to some 12 or 15 years ago the Muntz metal sheathing used, all of which came from leading manufacturers of the United Kingdom, proved an admirable protection, and could be relied upon as effective for at least 20 years,

Since that time, however, it has been very unreliable, as it sometimes fails completely in 6 months.

Without protection ironbark is readily attacked by marine posts and is quickly destroyed. For some years it has been the practice of the Harbours and Rivers Department to apply a strong solution of arsenic, 1 lb., carbonate of soda 2 lbs., dissolved in 4 gallons of water, to the surface of the pile, followed, when dry, by a solution of sulphate of copper, both solutions being employed liberally before sheathing with Muntz metal.

From test pieces, each 4 inches by 4 inches of hardwood, put down in Moreton Bay, off the mouth of the Brisbane River, about 1895, treated with the above solutions, it was found that the poisoned timber was not attacked for 4 years, the control pieces being destroyed in 1 year. It was concluded, therefore, that a pile so treated would resist for a couple of years at least, if the sheathing were damaged, and, as the cost of the poisoning is trifling, it is done, but this treatment is not relied upon as a protection to a greater extent than is above indicated.

Turpentine.—Is used for fender piles and for main piles in structures where small first cost is a consideration. It is driven with the bark on, and is never dressed and sheathed or treated in any way. Experience concerning this timber in Queensland is less favourable than appears to be the case in New South Wales. It offers some resistance to attack, but it varies greatly in this respect.

Swamp Mahogany, which grows in S.E. Queensland, has been largely used for main piles, and in many instances it has proved resistant to attack, but not at all times. As the resistance is probably due to a resin contained in the timber, this may vary with the nature of the ground on which it grows. Certainly it does not invariably prove resistant. So far as the writer's observation goes it is subject to attack by limnoria to a greater extent than by teredo. Piles over 40 feet in length are not obtainable, and it is becoming somewhat scarce.

Titree.—Has been used to some extent for piles on the northern coast of Queensland. It possesses some resisting properties, but it cannot be said to be resistant in a satisfactory sense.

As with Turpentine and Swamp Mahogany, but in a lesser degree, the resistance of Titree is vary variable. In a structure half or more of the piles may resist for 10 years, the remainder may not last more than 4 or 5 years.

Cypress Pine.—This timber undoubtedly resists the attack of all marine insects or worms; many piles to the writer's knowledge have not been attacked in 25 years. Being a soft wood, however, without much strength as compared with hard wood, its usefulness is limited to places where it is not subjected to much strain.

Apart from the question of structure it may be mentioned that Cypress pine (*Callitris robusta*) and She pine (*Podocarpus elata*) are used in Queensland waters for sheathing barges, punts, etc., in lieu of metal sheathing, with great success; the sheathing is in the shape of sawn boards usually $1\frac{1}{4}$ inch thick, and both timbers named appear to be absolutely resistant to insect attack. The She pine grows over large areas in Queensland, but not in abundance. Cypress pine also occurs

over a considerable area, but the timber is not obtainable in very large quantities.

Beams and Decking.—The hardwoods named are used for all superstructures, and their durability is considerable. Usually decay commences in beams after 10 years, where the suncracks and splits in girders, caused by the deck spikes, afford a lodgement to dirt and moisture producing fungoid rot. Even in such cases, however, it is rare to find more than 20 per cent. of the section decayed, and in the large majority of cases, girders and beams of good hardwood can be relied on for at least 20 years' service. A greater variety of the hardwoods is used for decking, which is almost invariably 4 inches thick, and on account of the wear from traffic and of less careful selection, decking usually requires some attention after 5 years, and general renewal after 10 to 15 years, according to the amount of traffic over it.

White ants attack parts of many of the timbers mentioned in the foregoing, but do not, except in rare cases, destroy them entirely. This insect will eat any sapwood it can find in the beam, and it sometimes enters a pipe or crack, enlarging the same and with the clay it brings with it promotes the destructive action of damp and fungus. It does not attack perfectly sound wood of the timbers named. It is easily disposed of, and the timber where the insect has appeared can be protected by spraying with the arsenical solution above mentioned.

Bracing.—The practice of bracing a piled structure above low water was formerly general. Such bracing was sheathed with Muntz metal, in the same manner as the piles, to the upper level of the insect activities—at Brisbane this level is at six-sevenths of the mean spring rise—and the sheathing was fastened with a Muntz metal bolt to the pile, a liner of 5 lb. sheet lead being interposed. This has generally proved satisfactory, the sheathing usually fails where bent over the brace, unless the precaution has been taken to well round off the corners of the latter. The writer has, however, for some years adopted the use of raking piles, inclined at an angle of 30 degrees from the vertical, in lieu of ordinary bracing above low water, retaining when necessary horizontal walings just above low-water mark, sheathed as described above.

The writer is of the opinion, based on his experience, that as regards attack by sea organisms in Queensland waters, treatment of timber by applied preservatives has a limited value, but cannot be depended upon for a greater period than 3 years at most. Treatment by injection is not applicable to hardwoods, so far as he is aware. In addition to the solutions named as having been used, one of baric chloride and Glauber's salt has also been tried to a limited extent, but it has proved less satisfactory than the arsenical solution.

ADDITIONAL REPORT.

In sending my former memorandum on timber used here, I stated my intention to forward particulars of some concrete works, but as the most important of these are situated at Bowen, Townsville, and at Cairns—3 or 4 days' steam north of Brisbane—I have not yet been able to go north to inspect them. At Townsville there is a reinforced concrete pier,

500 feet by 125 feet, built during 1912–13; and at Cairns the wharfage is 1,200 feet by 80 feet, also in reinforced concrete, built during the period 1911–15. At Gladstone we built a jetty in 1908.

So far as I am aware, these structures are good. At Bowen the reinforced concrete work consists in one extension of the jetty head 250 by 70 feet, and a new railway approach to carry the rolling stock from shore to the head—a distance of about 2,600 feet. I built this approach with concrete piles and headstocks and hardwood superstructure, finishing it in January, 1916, and I had the piles and headstocks well tarred, as well as the whole underside of the jetty extension. My reason for so doing was purely precautionary, but sufficient time has not yet elapsed to yield any proof of the value of the process. Two of the piers were not tarred, to serve as test controls.

In a small reinforced concrete wharf at Brisbane, completed a few months ago, I also for the same reason tarred the piles, beams, and the whole under-side of decking. My opinion is that tar if applied sufficiently hot will seal any pores.

In all the foregoing cases of tarring it has been applied from the level of high water. Such cases as I have seen of cracks, or rust, have invariably been above that level, and if a pile is well made, with mortar of proper strength, and not broken or injured in driving, there is in my opinion very little, if any, probability of the occurrence of corrosion in the steel below high-water level. It is, if I may express the opinion, much more necessary to protect reinforced cement from the action of moist air than from the action of water; and for want of better material I have used tar—obtained from a tar distillery.

I am now able to supplement my former report with notes on the concrete structures in Queensland.

CAIRNS.

This pier is situated on Trinity Bay, east coast of Australia, in latitude 16° 55½′ S. The inlet shores are mud flats covered for the most part with mangroves. The fresh water discharge is negligeable, but short-period floods may occur during the wet season—from January to March.

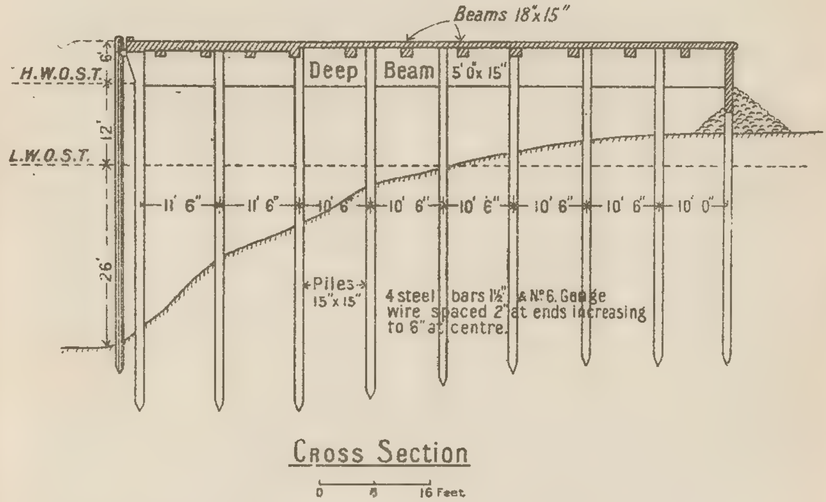
The wharfage consists of a continuous wharf 1,200 feet long by 80 feet wide, with a depth of about 26 feet alongside. It is built as shown on diagram. In building the outermost 600 feet the piles were increased to 18 inches by 18 inches and the beams were haunched.

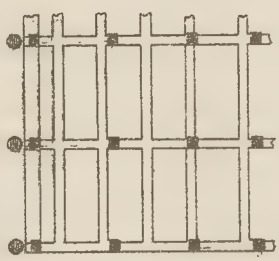
Piles. Section A, built in 1912 with piles, each 15 inches by 15 inches, to the number of 147, of which thirty show signs of corrosion.

Section B, built in 1913 with piles of the same size, to the number of 189, of which twenty-four show signs of corrosion.

Sections C and D, built in 1914 *and* 1915 *respectively* with piles, each 18 inches by 18 inches, show so far no defects. In sections A and B the 1½-inch steel bars had 1½-inch cover of concrete; in sections C and D there were 2 inches of cover. The corrosion in the pile steel occurs from the lower edge of the deep beam, down to about high-water level, at the

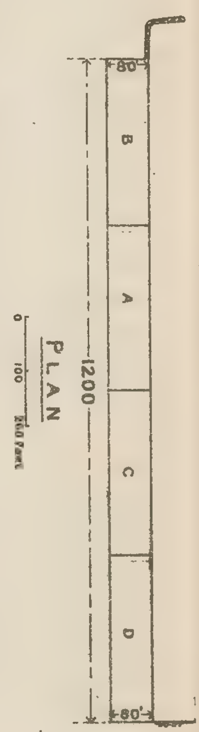
FIG. 23.





Pile Concrete
Cement....2
Sand......3
Stone.....5

Deck & Beams
Cement....3
Sand......5
Stone.....8



BRISBANE, QUEENSLAND.

Details of Cairns Wharf, Trinity Bay.

Constructed in Reinforced Concrete.

corners. In the worst cases a "splinter" of concrete, about 12 inches long, has become cracked, more or less, but few piles show more than slight cracks a few inches long at one or two corners. The diagram illustrates the details of construction, see Fig. 23.

The first cracks appeared in section A during 1914, about 2 years after building. The remedial measures taken were to break off the cracked concrete, clean the corroded steel, and plaster up the defect with mortar of equal parts of cement and sand. In a few cases corrosion has again occurred in the repaired places.

A few of the deep beams showed corrosion where the steel had sagged in the forms. The places were cut out and replastered. As in the case of the piles, a few of these patches have again become cracked by corrosion. So far no deterioration has been observed in the intermediate beams and deck slab. In all the above work the concrete, when the forms were struck, was cement washed.

TOWNSVILLE.

This pier is situated on Cleveland Bay, latitude 19° 15½′ S. There is no fresh water discharge of appreciable amount. The structure is 500 feet long by 125 feet wide, and it was completed in 1913.

The piles are 18 inches by 18 inches with about 1¾ inch of cover of concrete. As in the case of Cairns, a number—about 60 per cent.—show cracks from the junction with the deep beams for about 18 inches down at the corners.

The remedial measures taken were to cut out the cracked concrete, clean steel, and coat it with linseed oil, then the repaired portion was plastered up and two coats of cement wash were applied finally. So far this patching seems effective. It differs from that first done at Cairns in the fact that the steel was oiled and that the work received a second coat of cement wash. No deterioration has been observed so far in the superstructure.

It is noteworthy that early in 1917 a fire occurred in the shed in this place. The shed, which is 300 feet long by 36 feet wide, was completely full of general cargo, just received from an oversea vessel, and it and the shed were completely consumed. Except for a blistering of the surface to a depth of 1 inch at the junction of the various bonds between the different days' work, no ill effect occurred to the pier.

BOWEN.

At the pier in Port Denison—Latitude 20° S.—the head was extended inwards in reinforced concrete for a length of 258 feet and a width of 67½ feet; the work was completed in 1916. The piles are 15 inches by 15 inches, with 1¾ inch cover of concrete. No cracks or rust stains have been observed in main piles, but in three or four of the raking brace piles there are a few cracks in the upper corners near the head.

Superstructure.—The whole of the eastern side was completed first, and at the junctions in the deep beams, which were stepped and well bonded, cracks have occurred in nearly all cases from the bottom nearly half way up. These look like contraction cracks and do not show rust stains.

The longitudinal beams are all sound except in three places when stirrups were displaced and had only $\frac{1}{4}$-inch cover and rust occurs at these places.

Deck Slab.—In several places the reinforcing bars ($\frac{3}{8}$ inch) had been allowed to sag to within $\frac{1}{4}$ inch of the under surface, and these have rusted. Remedial measures are in progress, and they consist in cutting out the cracked concrete, cleaning the steel and re-mortaring the defects.

Just previous to their completion, in 1916, I had the under surfaces of this wharf and the piles above high water coated with distilled tar. Where the steel in the deck slab and beams had been displaced within $\frac{1}{4}$ inch or $\frac{3}{8}$ inch of the surface, the tar failed to protect it.

GLADSTONE.

An extension of 200 feet in length, in reinforced concrete, to the existing jetty at Gladstone, Port Curtis, Latitude 23° 50¼′ S., was built in 1908 by contract. The piles, 15 inches by 15 inches, the ordinary beams and the deck slab were designed to carry a test load of 7 cwt. per square foot. The diagonal bracing was mortised into the piles above low-water level. The depth alongside is 24 feet at low water, and the tidal rise is 12 feet. One raking pile was added at corner. The piles are in good condition, but in a few cases, perhaps 5 per cent., rust spots near the head above high water were cut out and re-mortared. The corrosion was not due to cracks, but to the fact that the steel was too close to the skin.

The superstructure was very badly built; faulty sand and stone off the beach were used, and the workmanship was bad. The main beams showed, by 1912, cracks in the underside several feet long and $\frac{1}{8}$ inch wide, due to corrosion, and this occurred in each bay. The cracked mortar was cut out and refilled, but this had to be done a second time in 1917.

BRISBANE.

The Fish Market wharf in Brisbane River, 20 miles from Moreton Bay, is situated in what is practically ordinary salt water. The latitude is 27° 28½′ S. The piles used are 15 inches by 15 inches, as at Bowen, and so far no deterioration has been observed. The diagram illustrates the details of construction, see Fig. 24.

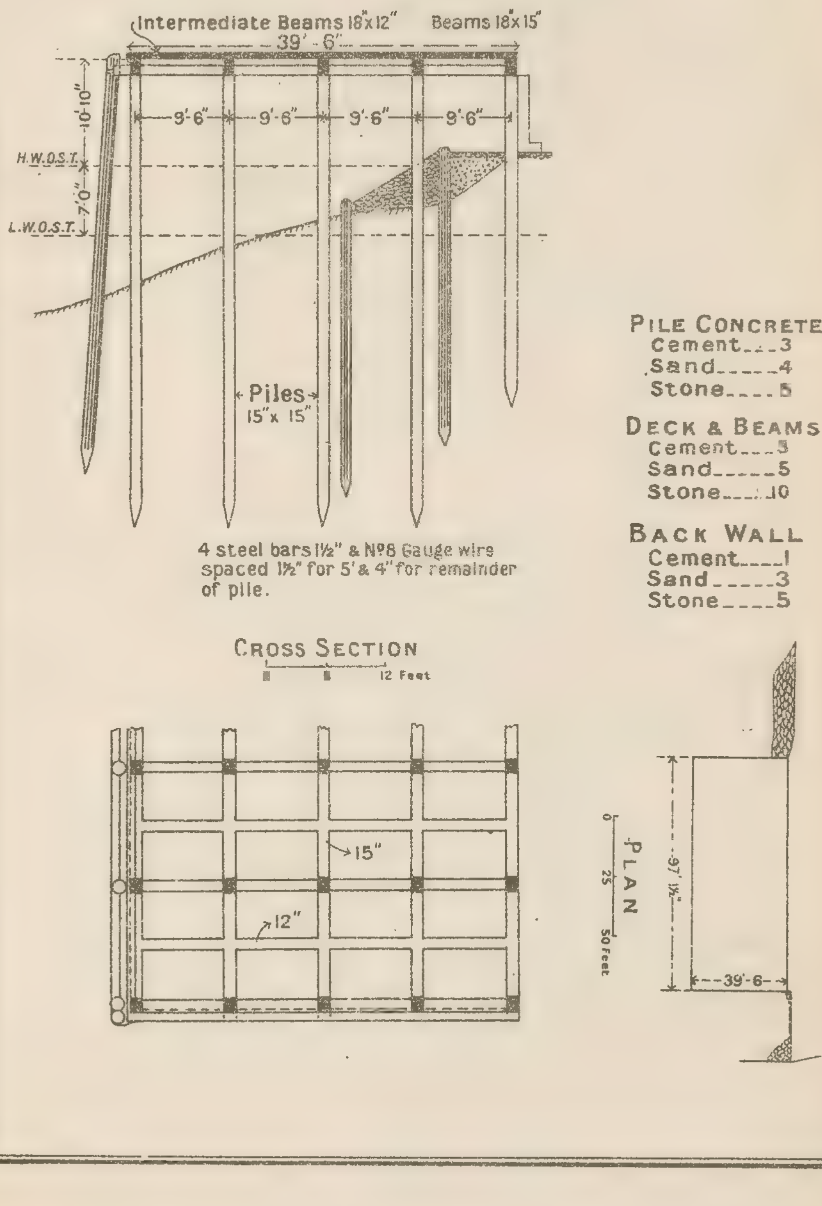
The piles above high water and the under surfaces of the superstructure were coated with distilled tar on completion.

It should be observed that I did not provide bracing in any of the above structures, other than raking piles and the deep beam. It is noteworthy that in all cases where piles have been affected it has been close to the junction with the deep beam. In building these beams, the pile head concrete is broken away, leaving the four steel bars, which then project up 3 or 4 feet into the deep beam, and are incorporated with it. There is thus a bond between old and new concrete in the pile at the junction, and probably it is at this point that the moisture enters and that the corrosion commences. In the Fish Market wharf at Brisbane, I discarded the deep beam.

FIG. 24.

BRISBANE, QUEENSLAND.

Section of Fish Market Wharf of Reinforced Concrete.



WEST AUSTRALIA.

JETTY AT DERBY, WEST AUSTRALIA.
Showing piles destroyed by teredo.

JETTY AT DERBY, WEST AUSTRALIA.
Showing piles destroyed by teredo.

WEST AUSTRALIA.

Jetty at Derby, West Australia.
Showing Cattle Race.

Jetty at Derby, West Australia.
Showing steamer alongside head of pier resting on mud.

WEST AUSTRALIA.

JETTY AT BROOME, WEST AUSTRALIA.

JETTY AT CARNARVON, WEST AUSTRALIA.

It is also possible that, in consequence of the pile heads being firmly held by the deep beams, the impact of a vessel may set up strains in the pile just below the beam, but I do not favour this explanation.

My conclusions, based on an experience of several years, are that in wharf, or similar constructions, a cover of 2 inches of concrete over the steel is desirable, that a concrete rich in cement should be used, and that very great care must be taken to prevent the dislodgment of the reinforcement. Notwithstanding precise instructions to the latter effect, there is evidence of corrosion due to carelessness in this work in nearly all the structures built in Queensland under my direction or advice.

It will be noted that for piles I have used a mixture of three cement, four sand and five stone, the last being hard stone chips, passing a $\frac{3}{4}$-inch gauge. All piles have been driven with a 2-ton monkey, using a thick pad; a dolly and helmet was not deemed necessary.

During 1916 I decided to apply distilled tar as a protective coating to keep out moisture, and used for this purpose one coat only. So far I am unable to state definitely that it is useful. After 2 years it shows a tendency to wear off, so to speak, or to thin out. I feel assured, however, that if two coats are applied in the first instance, this treatment will have some value, and I propose to continue its use.

PERTH, WEST AUSTRALIA.

By JAMES THOMPSON, B.E., M.Inst.C.E., Engineer-in-Chief.

I REGRET the delay in furnishing information detailing the effects of sea organisms in the destruction of local timbers in the structures under my charge, but it has not been possible to arrange for the shipping of the specimens—these will be sent as opportunity offers—meanwhile, I thought it better to forward my report, together with photographs.

In addition to the above statement, I have the following remarks to make in connection with Muntz metal sheathing: This is effective, provided the metal is a homogeneous alloy. If there is any segregation, however, of the zinc and copper, the zinc rapidly disappears, owing to electrolitic action, and the metal is destroyed and can easily be crumbled between the fingers.

This also applies to Muntz metal bolts, the metal from which can be pared off with a knife, but, being thicker, more time is needed to destroy them completely. The homogeneity of the alloy can only be determined by the microscope.

Muntz metal sheathing has not been used in the temperate zone, but much has been employed in the tropics, where the warmth of the water increases the rapidity of the electrolytic action, and, in consequence, this sheathing is not reliable.

Where sheathing is used on piles, the waling and bracing timbers attached to the sheathed portion of them are rounded out to a depth of 1 inch to $1\frac{1}{2}$ inch to fit the pile, in order to avoid cutting the metal. Holes through Muntz metal, for bolts, are made the bare diameter, and the bolts are driven through.

STATEMENT "A"—TIMBER STRUCTURES AT VARIOUS PORTS.

1. Name of Port.	2. Conditions of Exposure.	3. Salinity of water affected by Fresh Water Discharges.	4. Is Water affected by Sewage or Chemical Discharge?	5. Specimens.	6. Destructive Effects of—*a.* Teredo; *b.* Limnoria; *c.* Other Sea Organisms.	7. Nature of Works affected.	8. Photographs.	9. Effect of applying Metal Sheathing.
WYNDHAM. Lat. S. 15° 28′; Long. E. 128° 06′. At head of Cambridge Gulf: 45 m. from sea. *Length*, 1890, 130′; Exten. 1899, 288′.	Tropical Temp. 45° to 114°. Tidal Range 24 feet. Average ann. rainfall, 34 inches falling from Nov. to Mch.	Appreciably so during wet season (Nov.–Mch.). Exact observations not made.	No.	Specimens	*a.* Numerous holes bored along grain of timber destroy effective cross section. Piles sheathed with Muntz metal. *b.* Not observed. *c.* Nil. Damage from teredo occurs from ground level to abt. 10′ above L.W.M.	Only timber used.	Photographs attached.	Muntz metal sheathing effective if metal is a homogeneous alloy.
DERBY. Lat. S. 17° 20′; Long. E. 123° 35′. At head of King Sound, 65 m. from sea. *Length*, 1st, 650 feet (1887); 2nd 1,072 feet (1901).	Tropical Temp. 45° to 114°. Tidal Range 36 feet. Average ann. rainfall, 30 inches falling from Nov. to Mch. Jetty dries at L.W. Spring Tides.	Possibly during limited period in summer. No exact observations made.	No.	Specimen No. 11.	*a.* Same as preceding. *b.* Exterior of piles eroded 3 or 4 feet above mud level. *c.* Same as preceding.	Only timber used.	Photographs, see Plates XIV. and XV.; see 6 & 7.	Same as preceding.
BROOME. Lat. S. 17° 58′; Long. E. 122° 15′. In Roebuck Bay, 2½ m. from sea.	Tropical Temp. 42° to 110°. Average ann. rainfall, 20 inches falling from Nov. to Mch.	No.	No.	Specimens	*a.* Destructive effects not so serious as in preceding localities, but still very real. Piles sheathed	Same as above.	Photographs, see Plate XVI.	Same as above.

Length, 1897, 2,260 feet.	Tidal Range 28 feet. Jetty dries at L.W. Spring Tides. Occasionally suffers from hurricanes during summer months.				with Muntz metal. *b.* Exterior of piles eroded 3 or 4 feet above ground. *c.* Same as preceding.			
PORT HEDLAND. Lat. S. 20° 19′; Long. E. 118° 36′. On Estuary 1½ m. from sea. *Length*, 1st Jetty, 1897, 360 feet; 2nd Jetty, 1909, 760 feet.	Tropical Temp. 102° to 114°. Average ann. rainfall, 10 inches falling from Nov. to Mch. Tidal Range 24 feet. Severe hurricanes occasionally occur in Summer months.	No.	No.	Specimens	*a.* Destructive effects very marked. Piles sheathed with Muntz metal. *b.* Destruction by limnoria not observed. *c.* Nil.	Same as above.	Photographs	Same as preceding.
POINT SAMSON. Lat. S. 20° 38′; Long. E. 117° 12′. In open waters. *Length*, 1904, 2,150 feet.	Tropical. Temp. 42° to 114°. Average ann. rainfall, 9 inches falling throughout year. Tidal Range 18 feet. Visited by hurricanes.	No.	No.	Specimens	*a.* Same as Pt. Hedland. *b.* do. *c.* do.	Only timber used.	Photographs	Same as preceding.
ONSLOW. Lat. S. 21° 40′; Long. E. 114° 59′. On open coast. *Length*, 1900, 1,120 feet.	Tropical. Temp. 42° to 115°. Average ann. rainfall, 9 inches falling throughout year. Tidal Range 8 feet. Subjected to hurricanes.	Slightly affected when Ashburton River is in flood.	No.	Specimens	*a.* Same as preceding. *b.* Same. *c.* Same.	Same as preceding.	Photographs	Same as preceding.

STATEMENT "A"—TIMBER STRUCTURES AT VARIOUS PORTS—*continued.*

1. Name of Port.	2. Conditions of Exposure.	3. Salinity of Water affected by Fresh Water Discharges.	4. Is Water affected by Sewage or Chemical Discharge?	5. Specimens.	6. Destructive Effects of:— *a.* Teredo; *b.* Limnoria; *c.* Other Sea Organisms.	7. Nature of Works affected.	8. Photographs.	9. Effect of applying Metal Sheathing.
CARNARVON. Lat. S. 24° 52′; Long. E. 113° 38′. In Shark Bay. *Length*, 1898, 4,603′.	Sub-tropical. Temp. 38° to 110°. Average ann. rainfall, 9 inches falling throughout year. Tidal Range 6 feet.	Slightly affected when the Gascoyne River is in flood.	No.	Specimens	Piles not sheathed. *a.* Destructive effects moderate. *b.* Damage small. *c.* Negligible.	Same as preceding.	Photographs, see Plate XVI.	Same as preceding.
GERALDTON. Lat. S. 28° 46½′; Long. E. 114° 36¾′. In Champion Bay: exposed to open ocean. *Length*, two Timber Jetties, 800 feet and 2700 feet, and Timber Viaduct, 4,200 feet.	Sub-tropical. Temp. 39° to 110°. Tidal Range 4 feet 6 inches. Average ann. rainfall 18 inches, falling from May to Sept.	Not affected.	No.	None available.	*Small Jetty*— *a.* Not known; *b.* Badly attacked; *c.* Not known. *Large Jetty*— Maintained by Rly. Dept. No information available in this Department. *Timber Viaduct*— Built 1916. Insufficient time elapsed for results.	Only timber and iron used.	None available.	Not used.
DONGARRA. Lat. S. 29° 17′; Long. E. 114° 55′. Exposed to open ocean. *Length*, Timber Jetty, 1,270 feet.	Sub-tropical. Temp. 39° to 110°. Tidal Range 4 feet 6 inches. Average ann. rainfall, 19 inches falling from May to Sept.	Not affected.	No.	None available.	*a.* Not known. *b.* Badly attacked. *c.* Not known.	Ditto.	Ditto.	Ditto.

FREMANTLE. Lat. S. 32° 03′; Long. E. 115° 54′. In mouth of Swan River, and subjected to ocean tides. Length of Timber Wharves: N. side, 4,821 feet; S. side, 5,249 feet.	Temperate. Temperature, 38°–108°. Tidal range, 6 feet. Average ann. rainfall, 30 inches falling from May to Sept.	During winter months the river floods affect the salinity of the water on the surface, probably to a depth of about 4 feet.	No; the Perth treated sewage discharges into the river about 12 miles above Fremantle, but the immense area of intervening estuary neutralises any effect. At Fremantle the town storm-water drains only discharge into the harbour.	Specimens:—Nos. 1-9	*a.* Destroy jarrah piles and submerged sawn jarrah in from 10 to 15 years, whilst Oregon pine is riddled within a year. *b.* Attack jarrah piles, but not with such destructive effect as teredo. *c.* None known.	Only timber and iron used, except where piles are protected by reinforced concrete casings. These latter have not been affected.	None available.	Not used.
BUNBURY. Lat. S. 33° 19′; Long. E. 115° 38′. Situated at mouth of Leschenault Estuary in Koombana Bay, and exposed to open ocean. Length of Quarantine Jetty (timber): 128 feet.	Temperate. Temperature, 34°–100°. Tidal range, 5 feet. Average ann. rainfall, 36 inches falling from May to Sept.	Same as Fremantle.	No; town storm-water drains only discharge into estuary.	Specimens	*a.* The jetty is maintained by the Bunbury Harbour Board, therefore no details are available; but it is known that jarrah piles are badly attacked by teredo, although not to same extent as at Fremantle. *b.* Have not seen any timber removed from the jetty, which has been attacked by limnoria. *c.* None known.	None, except stone breakwater.	Ditto.	Ditto.

STATEMENT "A"—TIMBER STRUCTURES AT VARIOUS PORTS—*continued.*

1. Name of Port.	2 Conditions of Exposure.	3. Salinity of water affected by Fresh Water Discharges.	4. Is Water affected by Sewage or Chemical Discharge?	5. Specimens.	6. Destructive Effects of— *a.* Teredo; *b.* Limnoria; *c.* Other Sea Organisms.	7. Nature of Works affected.	8. Photographs.	9. Effect of applying Metal Sheathing.
BUSSELTON. Lat. S. 33° 38¾′: Long. E. 115° 20½′. In Geographe Bay, exposed to open ocean. Length: Timber jetty, 6,667 feet.	Temperate. Temperature, 32°–99°. Tidal range, 5 feet. Average ann. rainfall, 31 inches falling from May to Sept.	Not affected.	No.	None available.	Jetty maintained by Railway Department. No information regarding condition of structure available in this Department.	Only timber and iron used.	None available.	Not used.
ALBANY. Lat. S. 35° 01¾′; Long. E. 117° 53′. Situated in Princess Royal Harbour, a land-locked arm of the sea. Length of Town Jetty (timber): 2,000 feet; Old Deep Sea Jetty (timber): 1,900 feet; New Jetty, off former (timber): 1,480 feet.	Temperate. Temperature, 35°–103°. Tidal range, 5 feet. Average ann. rainfall, 36 inches falling from April to October.	Not affected.	No; storm-water drains only discharge into harbour at Town Jetty.	None available.	Jetties maintained by Railway Department. Karri piles driven in old Deep Sea Jetty 30 years ago have been completely destroyed by sea organisms. These failed about low-water. The Town Jetty, built of jarrah 30 years ago, is still standing and in regular use. The tarred jarrah piles in New Deep Sea Jetty have been emplaced 2 or 3 years only.	Ditto.	Ditto.	Ditto.

STATEMENT "B."—"EXPERIMENTS."—1.

1. Name of Port.	2. Class of Timber.	3. Nature of Preservatives (if any).	4. Analysis of Preservative.	5. Manner of applying Preservative.	6. Weight of Timber.	7. Specimen pieces of Timber Tested.	8. Unused Sound Specimens.	9. Dates and Duration of Tests.	10. General Result.
GERALDTON.	Jarrah and karri piles in Timber Viaduct.	Powellising process, Tarring and Charring.	Not available.	Karri piles boiled in Patent Powellising Mixture. Jarrah piles and braces boiled in coal tar for 30 mins. or over. Jarrah piles charred in open fire.	No records kept.	None available.	Specimen	Timber Viaduct constructed in 1916-17.	Experiments too recent to prove results yet.
FREMANTLE.	(*a*) Jarrah.	Powellising Process.	None available.	(*a*) Timber boiled in Patent Powellising Mixture, 5 parts water, 1 part molasses $2\frac{1}{2}\%$ arsenious oxide.	No records.	,,	Specimens.	(*a*) Powellised jarrah emplaced in 1909 and examined 1911.	(*a*) A failure.
	(*b*) Jarrah.	Tar.	,,	(*b*) Timber boiled in coal tar for 30 mins. or over.	,,	,,	—	(*b*) Tarred timber submerged 19th May 1911, examined 26th November 1915.	(*b*) Success except where coating of tar had been rubbed off and teredo attacked.
	(*c*) Jarrah.	Charred.	,,	(*c*) Timber charred in open fire.	,,	,,	—	(*c*) Charred do.	(*c*) Success.
	(*d*) Jarrah.	Charred and Tarred.	,,	(*d*) Combined application of (*b*) and (*c*).	,,	,,	—	(*d*) Charred and tarred do.	(*d*) Success.
	(*e*) Oregon and Jarrah.	Neuchatel Asphaltum Coating.	,,	(*e*) Oregon timbers immersed in boiling asphaltum, also jarrah piles coated with ditto. by means of a brush.	,,	,,	—	(*e*) 1913 to 1915 (2 yrs.), piles driven 1912 still under test.	(*e*) Timber failure. Piles still standing in quay apparently good.

STATEMENT "B."—"EXPERIMENTS." 1.—(*continued*).

1. Name of Port.	2. Class of Timber.	3. Nature of Preservatives (if any).	4. Analysis of Preservative.	5. Manner of applying Preservative.	6. Weight of Timber.	7. Specimen Pieces of Timber Tested.	8. Unused Sound Specimens.	9. Dates and Duration of Tests.	10. General Result.
FREMANTLE (*contd.*)	(*f*) Jarrah piles.	Concrete casings.	None available.	(*f*) Described in Statement C.	No records.	None available.	—	(*f*) Casings emplaced on piles in 1911 and 1912 still under test.	(*f*) No visible sign of deterioration.
	(*g*) Jarrah.	Smith Irvine Metallic Process.	,,	(*g*) Timbers treated privately by Patentees.	,,	,,	Specimen	(*g*) Submerged 8th June 1914, examined 15th June 1917.	(*g*) Absolute failure.
	(*h*) Jarrah.	Haddy's Specific.	,,	(*h*) Painted with Specific externally, and after emplacement a hole was bored in centre of top of pile and filled with Specific.	No records kept.	,,	,,	(*h*) 2 years.	(*h*) Failure.
	(*i*) Nor'-West pine.	None.	,,	(*i*) —	,,	Specimen No.	,,	(*i*) 1914–1917, 3⅓ years.	(*i*) Success. No deterioration.
	(*j*) Jarrah piles.	None.	—	(*j*) —	,,	—	—	(*j*) 1896–1911, 15 years.	(*j*) Failure.
BUNBURY	Jarrah piles in Main Jetty.	Tar.	None available.	Boiled in coal tar for 30 minutes or over.	,,	None available.	See Specimen for Fremantle	Tarred jarrah used in repairs of Main Jetty about 4 years ago. Not yet examined.	
	Jarrah piles in Quarantine Jetty.	Charred.	,,	Charred by open fire.	,,	,,	,,	Quarantine Jetty constructed, 1917.	Experiments too recent to give results yet.
ALBANY	Jarrah piles in New Deep Sea Jetty.	Tar.	,,	Jarrah piles boiled in coal tar for 30 minutes or over.	,,	,,	,,	New Deep Sea Jetty constructed in 1915.	No results yet available.

STATEMENT "C."—CONCRETE OR REINFORCED CONCRETE.

1 and 2. Nature and Character of Defects and History of Structure.	3. Condition under which Works were Executed.	4. Present Condition of Concrete.	5. Character of Reinforcement.	6. Composition of Concrete.
FREMANTLE. No defects yet in evidence.	Casings as now used in North and South Quays are made of concrete composed as given under 6, and reinforced with wire netting, &c., particulars of which are shown under 5. The concrete is hand mixed with fresh water, and casings are allowed to stand for at least 3 months after construction, for seasoning purposes, before being emplaced. Casings are made in 4-feet lengths, with an internal diameter of 2 feet, and the thickness of concrete is $1\frac{1}{8}$ inch; socket joints are provided. In connection with the emplacement of casings, special gear is used for lowering them into position, the bottom length being slipped over pile first and lowered until socket end is near water line, the succeeding lengths are then slipped over until required length is obtained, then the whole column is lowered on to a cleat fixed on the pile at required depth, or on to bottom, dredged to required depth, and filling is then tipped through open superstructure of the wharf to a height of at least one foot above the bottom of casing. The space between pile and casing (varying from $\frac{1}{2}$ inch to $4\frac{1}{2}$ inches) is then filled with sand, and a concrete plug is inserted on the top, with allowance for a small inspection hole through which an examination can be made from time to time.	(*a*) No deterioration visible. (*b*) Ditto. (*c*) Ditto.	Reinforcement consists of wire netting of No. 15 wire and 2 inch mesh and plain steel wire No. 8 gauge. Netting is bent to cylindrical shape on a suitable drum of required size and the plain wire is wound round the netting to form a continuous spiral reinforcement with a pitch of 2 inches.	Concrete used in casings is composed of Portland cement and sand in the proportion of 1 to 3.

So far as my experience goes, charring and boiling in tar confer a large measure of immunity against teredo and limnoria attack. Shellfish also attack piles and submerged timber, but they penetrate to no great depth.

I have not tried impregnation with creosote, because the native timbers are dense in their texture, and therefore the impregnation would only be slight.

In regard to charring, a method has lately been patented by an Australian—Mr. J. E. Cunningham. His process is to smear the timber to be charred with crude petroleum and then to apply heat by means of a blow-lamp. This produces a fine, even char. The principal advantage that I can see in this process is that if the timbers are previously charred by fire, any abrasions that may occur through handling can be made good by this means, or, in the case of piles, injuries in driving can be re-charred. In other timbers, this can be effected after they have been placed in position

SYDNEY HARBOUR.

By H. D. WALSH, B.A.I., M.Inst.C.E., Commissioner and Engineer-in-Chief, Sydney Harbour Trust.

Timber Wharf Construction.—In Sydney Harbour there are three marine organisms that attack and destroy timber, the teredo, which is locally called the cobra, the limnoria, and the sphæroma. The teredo, sometimes called "the ship-worm," is the most destructive. It grows to a considerable size in this port, and bores holes up to about $\frac{3}{4}$ of an inch in diameter, working very rapidly in certain kinds of timber. Hardness of wood affords no protection; ironbark, which is very hard and close grained, is destroyed almost as rapidly as pine. The teredo attacks the piles from about half-tide line to the bottom of the harbour, without much discrimination. It shows decided preference for some kinds of woods and relative aversion to others, but no local timber is altogether immune.

Turpentine (*Syncarpia laurifolia*), which can be obtained in straight lengths up to 90 feet, and is otherwise suitable for piles, has been proved to be very nearly immune from the attacks of teredo. Turpentine is durable both in the water and above it, but it has a fissile grain and requires protection from the direct rays of the sun, since dry heat is apt to cause cracks. It weighs about 56 lbs. per cubic foot and has a modulus of rupture of about 10,000 lbs. per square inch, and a modulus of elasticity of about 1,800,000 lbs. per square inch.

Turpentine is seldom used for capsills or girders, but where it has been tried, as for instance in a wharf at the Naval Dockyards, Cockatoo Island, it has proved satisfactory. It is used for walings and bracings below high-water level, and lasts in such situations better than any other timber available for the purpose. Turpentine piles are driven with the bark on. The trees are ringed in the forest and left standing for a few weeks before being cut, to enable the sap to escape, thereby causing the bark to become firmly attached. By this method very little of the bark becomes damaged in transit.

PORT JACKSON, NEW SOUTH WALES, AUSTRALIA.

Eastern Side, No. 1 Berth, Pyrmont.
Turpentile piles unsheathed and fender pieces. 28 years old.

Alexandria St. Ferry Wharf, Lane Cove. 28 years old.
Turpentine piles and walings showing evidence of attack by teredo and limnoria.

PORT JACKSON, NEW SOUTH WALES, AUSTRALIA.

FIG TREE FERRY WHARF, LANE COVE. Over 25 years old.

Near view of turpentine waling of landing stage showing ravages of teredo.

FIVE DOCK BAY TEST PILES. 12 years old.

Unprotected turpentine pile showing limnoria and teredo holes in sapwood. Wood otherwise sound.

During the past 17 years I have drawn great numbers of turpentine piles, after service ranging from 10 to upwards of 40 years. Not more than 10 per cent. of these were unfit from all causes for further service, and of those unfit less than one-half the deterioration was due to teredo. For some unknown reason an occasional turpentine pile will be attacked by teredo while others surrounding it remain untouched, see Plates XVII. and XVIII.

The *Limnoria lignorum*, which is small in size, perforates timber from the outside working generally in a radial direction. The holes vary from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch in diameter, and are so numerous that only a thin film of wood is left between them. The depth of the boring seldom exceeds $1\frac{1}{2}$ inch. The film of wood between the holes decays, or erodes away slowly, and the limnoria continues the boring towards the heart of the pile until it is destroyed.

The limnoria operates chiefly at and about low-water mark and again, but to a lesser extent, at the junction of the pile with the ground surface. It is common in an old wharf to see a pile thus eaten through at low-water mark, the top hanging to the head-stock.

As with the teredo, the limnoria shows decided preference for certain timbers and more or less aversion for others. Soft woods such as pines and cedars are very rapidly destroyed. Both organisms may attack together, and it is not unusual to see the large holes of the teredo surrounded by the smaller ones of the limnoria. The teredo does not bore radially, nor are the holes straight, they pass downwards in a devious course fully 24 inches deep.

Experience has shown that turpentine timber has considerable powers of resistance to limnoria. With the bark intact, the protection afforded is almost perfect. Without the bark the attack is very slow since the sapwood affords a large measure of protection. After periods of about 30 years' service, many piles of 14 inches diameter have not been reduced in diameter by limnoria by more than 4 inches at low-water line, and by about 2 inches at the ground line.

The exposed heart of turpentine, on the contrary, is very quickly destroyed by limnoria. Thus the ends of braces and the bottoms of fender-pieces, at and below low-water mark require protection. And walings containing heartwood exposed on one surface are soon reduced to a shell.

The sphæroma, which is about $\frac{1}{4}$ inch in length, very closely resembles the common wood-louse and, I believe, belongs to the same species. It pits the surface of the wood with a number of oval-shaped depressions somewhat larger than itself, the walls between which seem eventually to break down. It is not seriously destructive as it works slowly and usually attacks only one side of a pile. The parts so attacked are always free from limnoria, which are many times more destructive, and there are always fewer teredo holes in the portion where sphæroma operate, so that although they actually destroy timber in the course of time, they in a measure afford protection against the more rapid and certain destruction of the teredo and limnoria. Curiously enough the sphæroma attacks soft sandstone in the same way. Whether the sphæroma discriminates

between one class of timber and another is not certain. They have not so far been seen at work on soft woods, but that may be because soft woods are so greedily attacked and destroyed by the limnoria. Turpentine is not altogether immune, but the bark affords valuable protection as long as it lasts. Piles of the eucalyptus species, driven without protection have in some instances been seriously damaged by sphæroma.

Up to the year 1901 it had been the custom to sheath with yellow metal the piles of all public wharves in Port Jackson. But for some time previous to that all brands of yellow metal were found to be very inferior in durability to the original Muntz metal and similar alloys. The deterioration in salt water was so rapid that no more than 2 or 3 years' protection could be counted upon, at about double the cost of an unsheathed pile.

In view of the failure of yellow metal it was decided in 1903 to discard it altogether. Since that date practically all the piles driven by me in wharf construction at this Port have been of unsheathed turpentine. The exceptions are a wharf built for the Railway Commissioners at Glebe Island, the piles of which were sheathed with yellow metal at that body's request; a wharf at Jones Bay, Pyrmont; and portions of a jetty at Woolloomooloo Bay. The last two do not properly rank as sheathed wharves, as the piles were of composite construction, consisting of a timber core surrounded with reinforced concrete cylinders, grouted up with rich concrete, the function of the pile being merely that of a supporting foundation for the concrete column in which it is incorporated.

Though all timbers are affected more or less by the action of marine borers, the resistant power of the various woods may be taken in the following order :—

1. Turpentine (*Syncarpia laurifolia*).
2. Brush Box (*Tristania conferta*).
3. Ironbark (*Eucalyptus paniculata*), Blackbutt (*E. pilularis*), Grey Gum (*E. punctata*), Blue Gum (*E. saligua*), Spotted Gum (*E. maculata*).
4. Oregon pine and soft woods.

Turpentine piles have been drawn after being in the water for 40 years and found to be nearly as good as when they were first driven; on the other hand turpentine piles in the same wharf, but presumably cut at the wrong season, have been found to be badly attacked.

Brush box will stand for 6 or 9 months without being much damaged, but ironbark and the other timbers are badly riddled by that time, and the soft woods are practically destroyed in 3 months.

The cutting action of the sand near the entrance of the port, where a ground swell exists, has the effect of reducing the sectional area of the piles at the ground level, but the speed of erosion is slow.

Sheathing with Muntz and other yellow metals.—Where this kind of protection is used, ironbark piles are generally selected. Their life is governed by the durability of the Muntz metal, which varies greatly in lasting power. In some cases this sheathing has been found to be sound after 15 years, and in others it has become brittle after 2 years'

PORT JACKSON, NEW SOUTH WALES, AUSTRALIA.

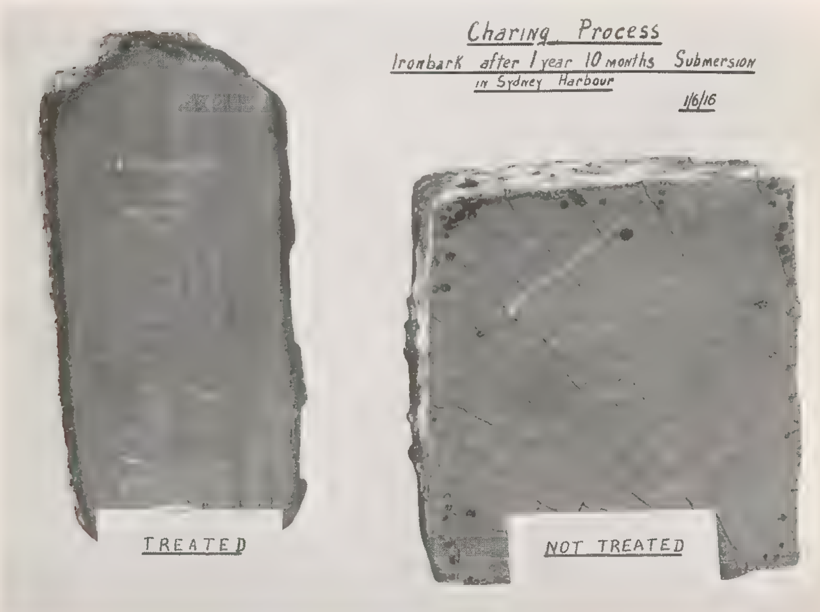
CHARRING TEST, WATSON'S BAY. 2 years 4 months old.

Near view of notch cut in upper end of ironbark pile. Note teredo holes marked by splinters in upper right-hand corner.

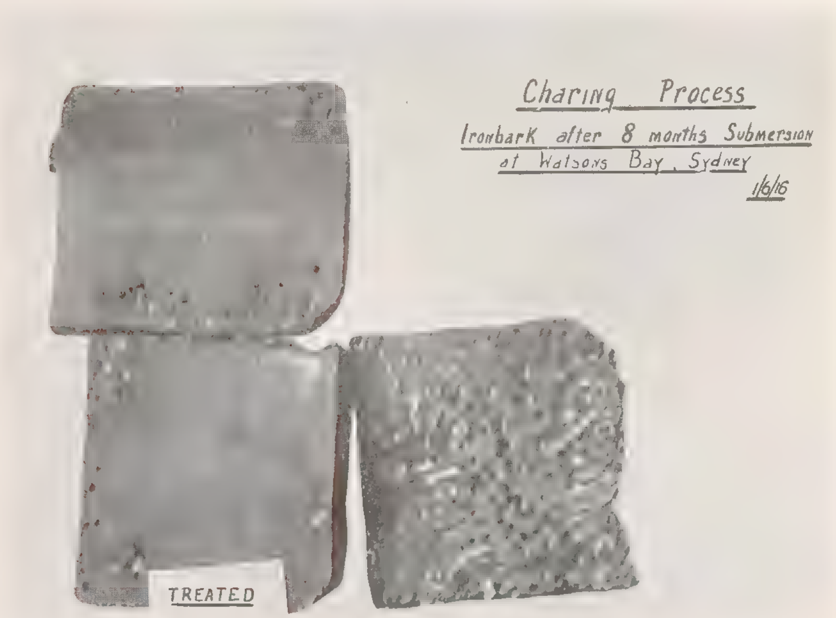
CHARRING TEST, WATSON'S BAY. 2 years 4 months old.

Near view of notch cut in centre of ironbark pile. No evidence of teredo action.

PORT JACKSON, NEW SOUTH WALES, AUSTRALIA.



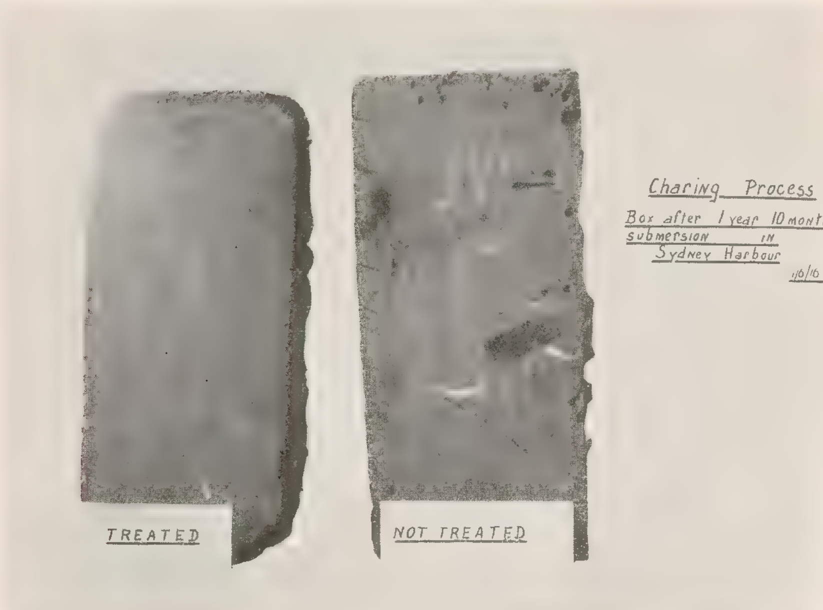
Specimens of Ironbark, Treated and Untreated, after 1 year 10 months' Submersion in Sydney Harbour.



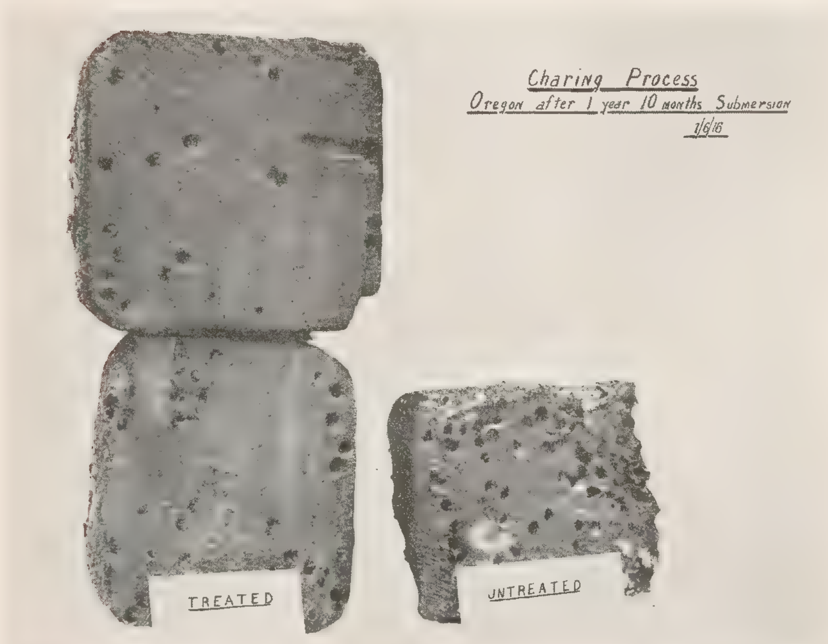
Specimens of Ironbark protected by Charring Process and Untreated after 8 months' Submersion in Sydney Harbour.

PLATE XXI.

PORT JACKSON, NEW SOUTH WALES, AUSTRALIA.



SPECIMENS OF BRUSH BOX, TREATED AND UNTREATED, SYDNEY HARBOUR.



SPECIMENS OF OREGON PINE, TREATED AND UNTREATED, SYDNEY HARBOUR.

submersion; the area most affected is that between wind and water. Yellow metal seems now to last better than it did 15 years ago.

Sheathing with concrete.—The piles (ironbark) are covered with Monier cylinders and the annular space is filled with concrete as already described. The oldest of the piles treated in this fashion have only been in service for 5 years, and beyond some rust spots, seen on the surface, there is no evidence so far of deterioration.

Powellising timber.—Eight years ago a number of piles and fenders were powellised and put into use. Various kinds of timbers were so treated, but in no case did there appear to be any improvement in the resisting powers of the timber.

Charring (or Carbo-teredo) process.—A number of tests extending over nearly 2 years were made by charring the surface of various timbers. The charring to a depth of from ¼ inch to ½ inch was carried out with large brazing lamps. The results for the period mentioned prove that, while it does not render the timber perfectly immune from the attacks of marine borers, charring certainly prolongs its life very considerably as long as the char remains on, see Plates XIX., XX. and XXI.

Lysaghts Wharf No. 6, Darling Harbour.—This wharf was built in April and May 1909 of various kinds of timbers, all of which had been powellised. The result after 8 years' service is as follows:—All the piles were found to have been attacked, the sapwood being eaten away by limnoria to a depth of ¾-inch to 2 inches. In several cases (notably the ironbark and stringybark piles) there was evidence of teredo action. The squared fenders on the northern side were in a fair condition, but those on the eastern side were badly bored with the exception of the grey gum near the corner.

Coal Jetties, Nos. 1 to 4 berths, Darling Harbour.—These were built about 28 years ago of turpentine piles. The photograph, Plate XVII., shows pile at bottom of steps, No. 3 berth—a portion of the bark is shown still adhering to the pile. The action of limnoria is pronounced but has not penetrated beyond the sapwood. There are no signs of teredo. The same remarks apply to other photographs taken at No. 1 berth, but there is evidence here of some teredo action in the sapwood which has been exposed by the limnoria attack.

Turpentine Pile drawn from former Parbury's No. 1 Jetty, Dawes Point.—This Jetty was 25 years old when it was demolished. The photograph sent shows general view of the pile with battens marking the low and high tide levels and the silt level.

Fig Tree Wharf, Lane Cove River.—This structure is over 25 years old. The photographs give a general view showing teredo action in an old ironbark pile now used as a girder, and also in the piles. Another illustration shows a detail of the bottom landing, and a third, Plate XVIII., a nearer view of the waling—all reveal more or less serious attacks by limnoria and teredo. These piles and walings are of turpentine.

A group of three piles were placed in Five Dock Bay, in the Parramatta River, in 1905 and withdrawn after 12 years' submersion. One of these, an unprotected ironbark pile, was badly attacked by teredo and limnoria. The second one was also ironbark, but was protected by a covering of

malthoid which was either eaten away, or worn off, between wind and water allowing the timber to be attacked, but to a less degree than in the unprotected ironbark pile. The third pile, an unprotected turpentine pile, was badly attacked by sphæroma, but not to any extent by other borers.

Charring Tests.—A test consisting of two ironbark piles charred to within a short distance of the ends was put down at Watson's Bay 25th November 1914. The piles should have been sunk in the sand so as to cover the untreated portions, but through some misunderstanding this was not done. However, the test shows the difference between the treated and untreated portions. These piles were removed on 9th March 1917. The uncharred portions were found to be badly attacked and the charred portions to a slight extent. These piles were only lightly charred.

Two sets of tests were also carried out in Darling Harbour. In the first set, pieces of ironbark, brush box and Oregon pine were cut in half, one half in each case was left untreated and the other half was charred under the supervision of the patentee of the Carbo-Teredo Process. A deep char was made. These pieces were bolted in pairs from a turpentine cross piece and the whole set was submerged under the Grain Jetty at Pyrmont on 20th July 1914, being lowered to within a few feet of the bottom. The tests were lifted on the 24th November 1914, and numerous young teredo were found on the outside surface of the timbers. The tests were resubmerged and lifted once more on 19th March 1915 and the ends of the timbers were cut off. The charred timbers were found to be untouched, while all the uncharred portions were attacked to some extent, the Oregon pine badly so. The test pieces lay on the wharf for 6 weeks and were then recharred at the ends and again submerged and left there until 1st June 1916 when they were brought to the surface and the ends were cut off and examined. Although the charred Oregon pine was attacked the charred ironbark and brush box were untouched.

The second test was a smaller one, and consisted of ironbark timbers only. After 8 months' submersion at Watson's Bay, the test was lifted, and the timbers were found to be severely attacked. The untreated timber was riddled, and the treated portions were injured in a less degree. These specimens were only lightly charred, which may account for the difference in the results from the first test, but there is no doubt that the teredo at Watson's Bay are particularly voracious.

A plan of Port Jackson is attached to this report. This plan shows the position in the port where the various tests referred to were made, see Fig. 25.

AUCKLAND HARBOUR.

By W. H. HAMER, M.Inst.C.E., Engineer to the Harbour Board.

Location.—Latitude, 36° 49′ 56″ south; longitude, 174° 47′ 57″ east.
Temperature.—

Mean temperature of sea-water: winter, 57° F.; summer, $65\frac{1}{2}$° F.
" " of air; winter, 60° F.; summer, 67·8° F.

FIG. 25.

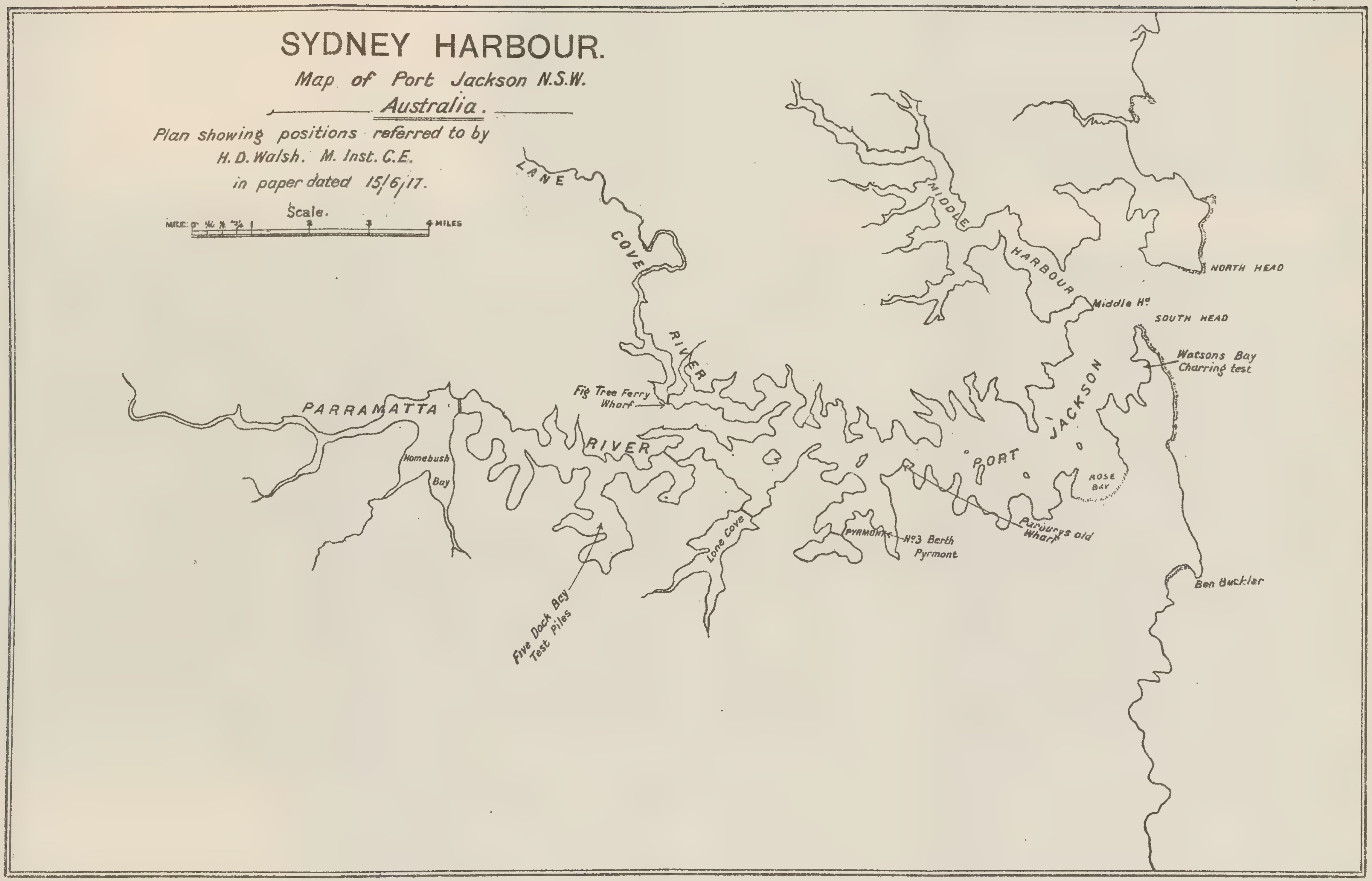
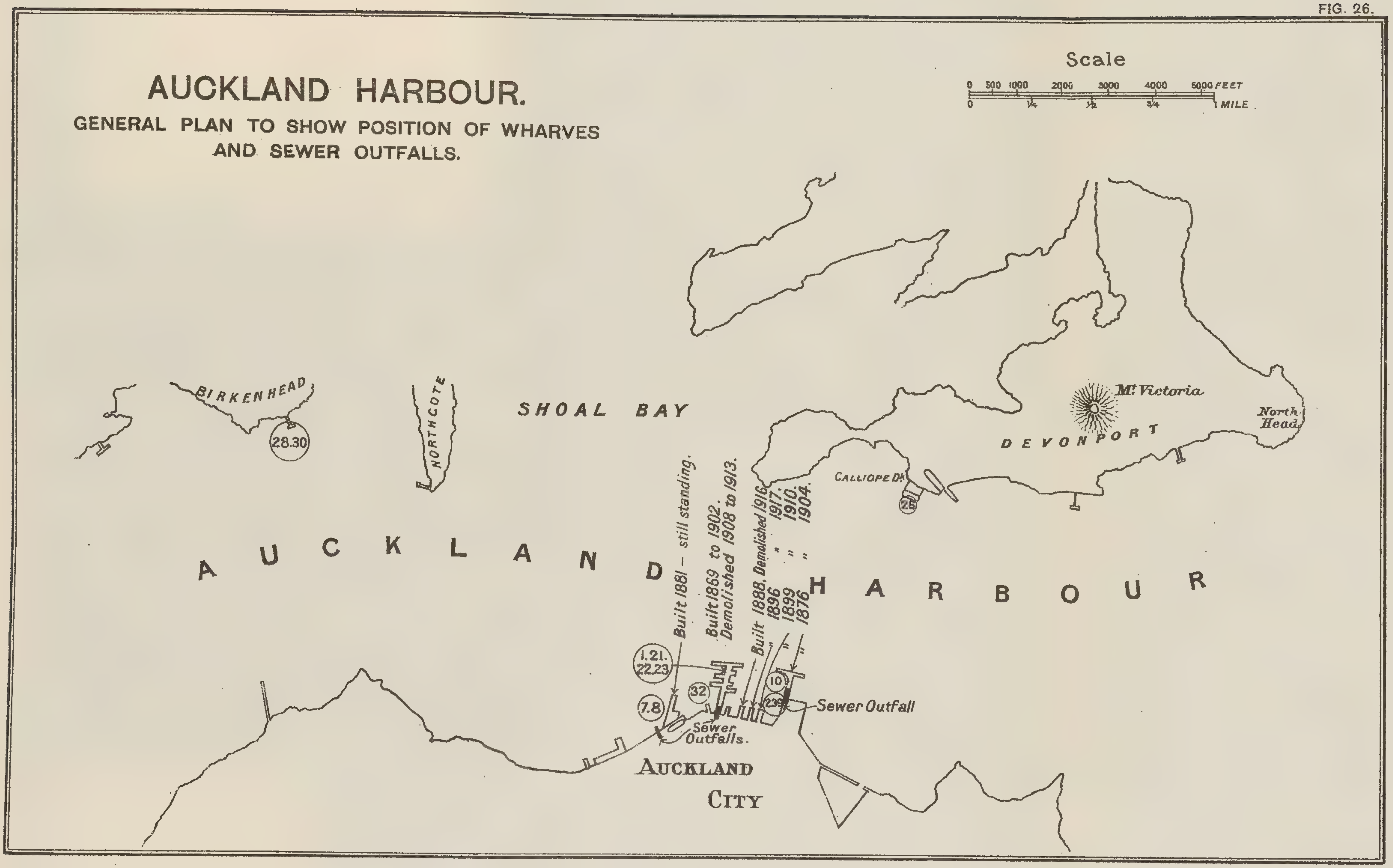

SYDNEY HARBOUR.
Map of Port Jackson N.S.W.
Australia.
Plan showing positions referred to by
H. D. Walsh. M. Inst. C.E.
in paper dated 15/6/17.
Scale.
MILE
MILES
LANE COVE RIVER
MIDDLE HARBOUR
NORTH HEAD
Middle Hd
SOUTH HEAD
Watsons Bay
Charring test
PORT JACKSON
PARRAMATTA RIVER
Fig Tree Ferry
Wharf
Homebush
Bay
ROSE BAY
PYRMONT
No.3 Berth
Pyrmont
Lane Cove
Five Dock Bay
Test Piles
Ben Buckler

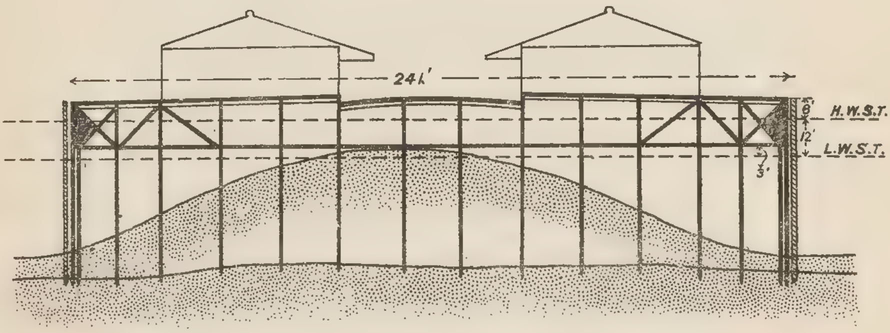
FIG. 26.



AUCKLAND HARBOUR.
GENERAL PLAN TO SHOW POSITION OF WHARVES AND SEWER OUTFALLS.
Scale
0 500 1000 2000 3000 4000 5000 FEET
0 1/4 1/2 3/4 1 MILE
BIRKENHEAD
28.30
NORTHCOTE
SHOAL BAY
Mt Victoria
North Head
DEVONPORT
CALLIOPE Dk
26
AUCKLAND HARBOUR
Built 1881 – still standing.
Built 1869 to 1902.
Demolished 1908 to 1913.
Built 1888. Demolished 1916.
1917.
1910.
1904.
1896
1899
1876
1.21.22.23
32
7.8
10
23
Sewer Outfalls.
Sewer Outfall
AUCKLAND CITY

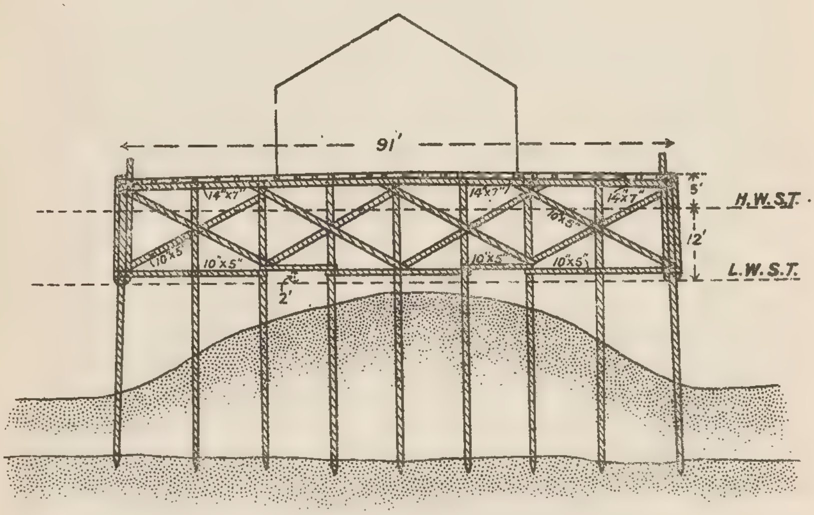
FIG. 27.

AUCKLAND N.Z.



Scale: 0 10 20 30 40 Feet

TYPICAL OF THE REINFORCED CONCRETE WHARVES AT AUCKLAND, N.Z.



Scale: 0 10 20 30 Feet

TYPICAL OF THE OLD TIMBER WHARVES AT AUCKLAND, N.Z.

Maximum temperature of sea-water: summer (Jan.), 72° F.
Minimum „ „ winter (June), 51° F.
Maximum „ of air: summer (Jan.), 73° F.
Minimum „ „ winter (June), 54° F.

Marine Growth.—A growth of limpets, barnacles, mussels, oysters, sponges, seaweed, and other forms of low vegetable and animal life commences on all kinds of stationary structures immediately, and soon attains a thickness of 2 to 3 inches. In 6 to 10 years this increases to 7 and 8 inches.

Tides.—Extreme range of spring tides, 12 feet; normal range of spring tides, 10 feet 6 inches; normal range of neap tides, 6 feet.

Sea-Water.—The sea-water is, generally speaking, clear, and has a specific gravity of 1·0252. The total solids are 34·62 grammes in 1000 cc., made up as follows:—

Sodium chloride	26·675
Magnesium chloride	3·547
„ sulphate	1·834
Calcium sulphate	1·462
Others not estimated	1·102

Sewer Outfalls.—Sewer outfalls now being diverted have hitherto discharged where shown on plan, see Fig. 26. An investigation of the timbers round about these outfalls did not show material difference in their destruction by marine pests. The volume of pollution was never great, and the dilution was large. The only fresh water entering the harbour is from storm-water overflows and natural surface drainage. This harbour is entirely an estuary, and the fresh water dilution is almost negligible.

Timber Structures.

Timber.—The first timber jetty at Auckland was constructed about 1852, and there is a record that this was renewed in 1876. From that date till 1903 all pier, jetty, or wharf structures were built entirely of timber, see Fig. 27. Since 1903 new works have been built of concrete, either in mass or reinforced.

Kinds of Timber.—The following kinds of timber have been tried as piles, braces, and walings:—

Local Name.	Botanical Name.	Where Grown.
Totara	*Podocarpus totara*	New Zealand.
Blackbutt	*Eucalyptus pilularis*	New South Wales.
Blue gum	*Eucalyptus globulus*	Victoria and Tasmania.
Turpentine	*Syncarpia laurifolia*	New South Wales.
Ironbark	(Probably the grey) *Eucalyptus paniculata*	New South Wales.
Jarrah	*Eucalyptus marginata*	West Australia.

All the above timbers, except totara and turpentine, would be destroyed in a year or two unless sheathed in copper, Muntz metal, or zinc.

If the sheathing is torn destruction commences rapidly; the teredo enters the timber and bores up the inside, rendering the protective sheathing useless.

The agents causing destruction are: (*a*) *Teredo saulii*; (*b*) *Limnoria lignorum*; (*c*) *Chelura terebrans.*

The two last appear to have been more recent importations than the former. The chelura is said to be less common than the limnoria, but both work together in the same piece of timber, totara is destroyed by them and turpentine is attacked.

The specimens forwarded, and the photos, etc., sent herewith, clearly show the nature of the destruction, which takes place generally between high- and low-water neap tides. A tide gauge is shown in some photos, zero in all cases is extreme L.W.S.T.

The plan of the harbour sent herewith gives dates of construction and demolition of various timber wharves, together with positions of sewer outfalls, see Fig. 26.

Briefly, it may be said that no timber is reliable in this harbour unless it is sheathed with protective covering and carefully maintained. This is costly, and the modern metal is not so satisfactory as that used in the earlier days. Below mud level the timber remains perfectly sound. In the last 15 to 20 years no sheathing has been placed on timber here, and northern totara and turpentine have been used only as buffer or fender piles.

The totara used must be red heart, and grown to the North of Auckland, New Zealand. Sapwood is at once attacked by teredo, but the heart is not badly touched, though none of it is free from destruction by limnoria or chelura.

Generally speaking the life may be stated as 15 years, though some piles resist longer than others; but maintenance becomes heavy after 12 to 15 years, particularly where outside piles of wharves, weakened by marine pests, are subject to the bumping of vessels.

12-inch by 6-inch and 10-inch by 5-inch lower walings and lower ends of braces of this timber meet on piles at from 3 to 4 feet above extreme L.W.S.T., and in 11 to 12 years these have become entirely useless for their purpose, the ends being completely eaten away by limnoria and chelura, and this damage continues up the brace to a level of 6 feet 6 inches above extreme L.W.S.T., see Plate XXII.

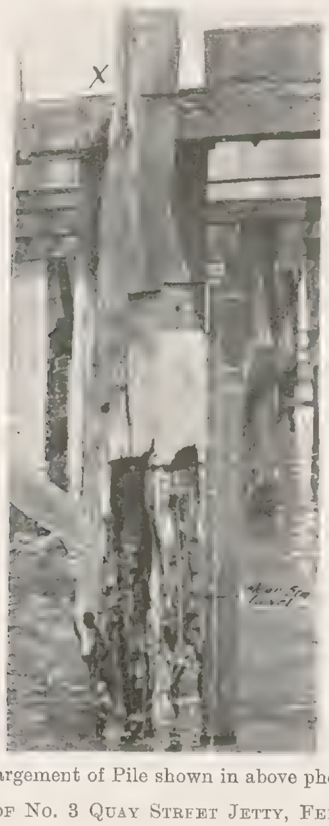
The tops of sheet piles driven in 1902 have been completely destroyed in 11 to 12 years at a level of about 3 feet above low water, and the seaward ends of totara braces, holding these piles back to tie piles, have become useless in the same period, thus demanding extensive and expensive renewals to considerable lengths of breastworks. The limnoria and chelura appear to be more destructive now than the teredo. Large holes are frequently eaten into piles leaving only a thin casing of the original surface of pile, see Plates XXIII. and XXIV.

Totara is a brittle timber and of little service except for use as piles, posts and building timber, etc. Its use as bridging timber has been discarded. Its weight dry is 34 lb. per cubic foot and as obtained commercially 45 lb. per cubic foot.

PLATE XXII.

AUCKLAND, NEW ZEALAND.

Quay Street Jetty built in 1896. All piles of Totara. Tide Gauge showing limits of destruction. Heights are above extreme L.W.S.T.



Enlargement of Pile shown in above photo.

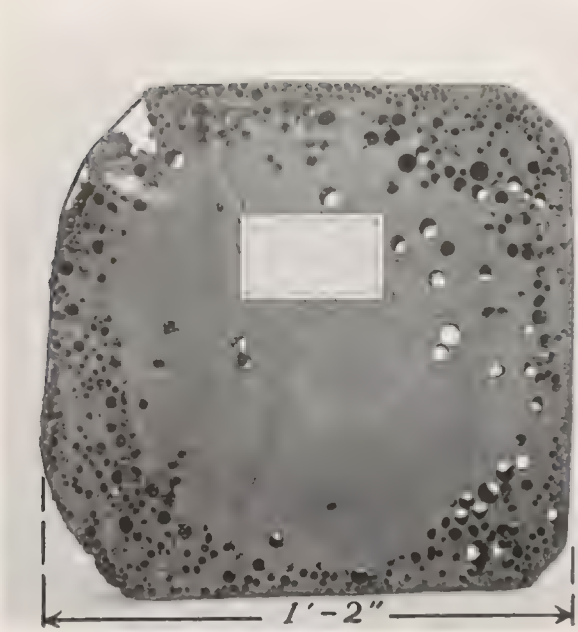
Demolition of No. 3 Quay Street Jetty, February, 1917.

AUCKLAND, NEW ZEALAND.

Totara piles, braces, etc., at Hobson's Wharf destroyed by *Limnoria lignorum*. Some piles wholly gone, and fish pieces placed both sides as shown in photograph. This wharf was constructed in 1881. Water level, about 3 ft. above L.W.S.T.

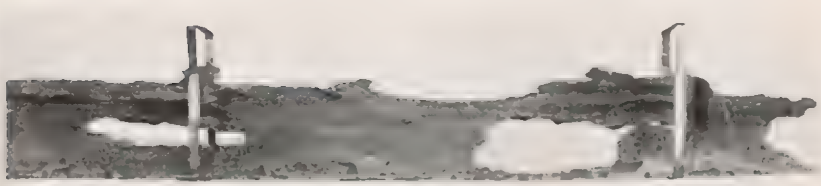
Timber under old railway wharf. Showing destruction by *Limnoria lignorum* and *Chelura terebrans*. This wharf was built 1876. Demolished 1907.

AUCKLAND, NEW ZEALAND.



Section of Totara pile after 27 years' immersion.

Totara almost destroyed by Chelura.



Portion of brace of Totara. Original size 10 inches × 5 inches. Destroyed by *Limnoria lignorum* or Gribble and *Chelura terebrans*. Taken from low landing, King's Wharf, after about 12 years' immersion. Metal bands show original size.

Its co-efficient S for cross breaking on 12 by 1 by 1 inch cantilever was a mean of 122 lb. on eight specimens. A pile 30 feet long, tapering from 13 inches to 10 inches square, has split on being dropped 15 feet sideways into water.

Turpentine fender piles have only been used here since 1908—(1) primarily on account of the good report from Sydney and New South Wales harbours as to their teredo-resisting properties; (2) their great size and length; (3) their economy as compared with local totara which was costly and increasingly difficult to get; and (4) the shorter time required to procure them. They were obtained from Port Stephens, N.S.W.

It is recommended that they be driven with their bark on, and this has been done as far as possible, but in handling and transhipment the bark is easily stripped, and many have been driven here without the bark.

The experience of their use has so far (9 years) been satisfactory; the limnoria and chelura have attacked them to a small extent, but there are very few teredo bores.

In a section cut from a broken stump 11 inches diameter, after 7 years in the water of this harbour, there were only half a dozen teredo bores on the extreme outside and one in the heart, where there had been a shake, and none of these holes exceed $\frac{3}{16}$-inch diameter. They were at a level 18 inches above L.W.S.T. and only on one side had the limnoria appeared, there it is eaten away to a depth of $\frac{1}{2}$- to $\frac{3}{4}$-inch.

Turpentine weighs dry $61\frac{1}{2}$ lbs. per cubic foot and as obtained commercially 69 lbs. per cubic foot. Its co-efficient S for cross breaking as a cantilever 12 by 1 by 1 inch was a mean of 238 lb. for seven specimens.

Its use is being continued in the form of spring fender piles and braces, and as buffer piles at rounded corners of concrete wharves, and it is preferred to totara on account of its better resistance to blow and shock.

Timber Floating Plant.—There are several stationary timber pontoons for floating stages and a number of timber punts in connection with dredging in this harbour.

Timber Pontoons.—Two launched in March, 1905, were constructed of totara planking up to 4 feet 6 inches from bottom and above that of kauri. They were sheathed on the outside all over with $\frac{3}{4}$-inch thickness of heart of totara. The hull was protected thus:—A layer of brown felt closely nailed on all edges, above this a covering of chenam (a thick mixture of fish oil and lime) $\frac{1}{4}$-inch thick, then over this $\frac{3}{4}$-inch totara sheathing.

One of these pontoons was examined after being 11 years in water. There was a blanket of marine growth consisting of oysters, mussels, sponges, and weeds on the underside about $7\frac{1}{2}$ inches thick. Limnoria had attacked a few of the bottom sheathing boards but not others. There was very little sign of the teredo.

Timber Punts.—These punts were built in 1909 of heart of kauri, sheathed with 9 by $1\frac{1}{4}$ inches red heart of totara.

The specification required that the whole outside surface should receive a coat of coal tar before the sheathing was put on. This was covered for 4 feet up from bottom with brown felt, having a lap of $1\frac{1}{2}$ inches on all

edges, secured with clout nails $1\frac{1}{2}$ inches long, driven 9 inches apart on edges, and scattered over the surface. This was next covered with No. 12 gauge sheet zinc, having a lap of 2 inches on all edges, secured by galvanised clout nails $1\frac{1}{2}$ inch long, driven 2 inches apart on edges and not more than 6 inches apart over remainder of surface. The totara sheathing was then fixed on this surface.

These punts are with exceptions slipped annually for examination. One allowed to go for 3 years was found to be quite sound and another after 6 years was generally good; small teredo had commenced to attack the totara sheathing. Generally it is found that the felt, chenam, and zinc are a sure protection and the totara sheathing forms a good cover to all these, providing they are regularly examined.

It has been noticed that a teredo will travel longitudinally along a piece of sheathing until it comes to the seam caulked with oakum or spun yard, at which point it will stop.

Concrete Structures.

To combat the destruction of timbers by marine pests after the year 1903, concrete in mass or reinforced was adopted, and works were carried out in the order given below:—

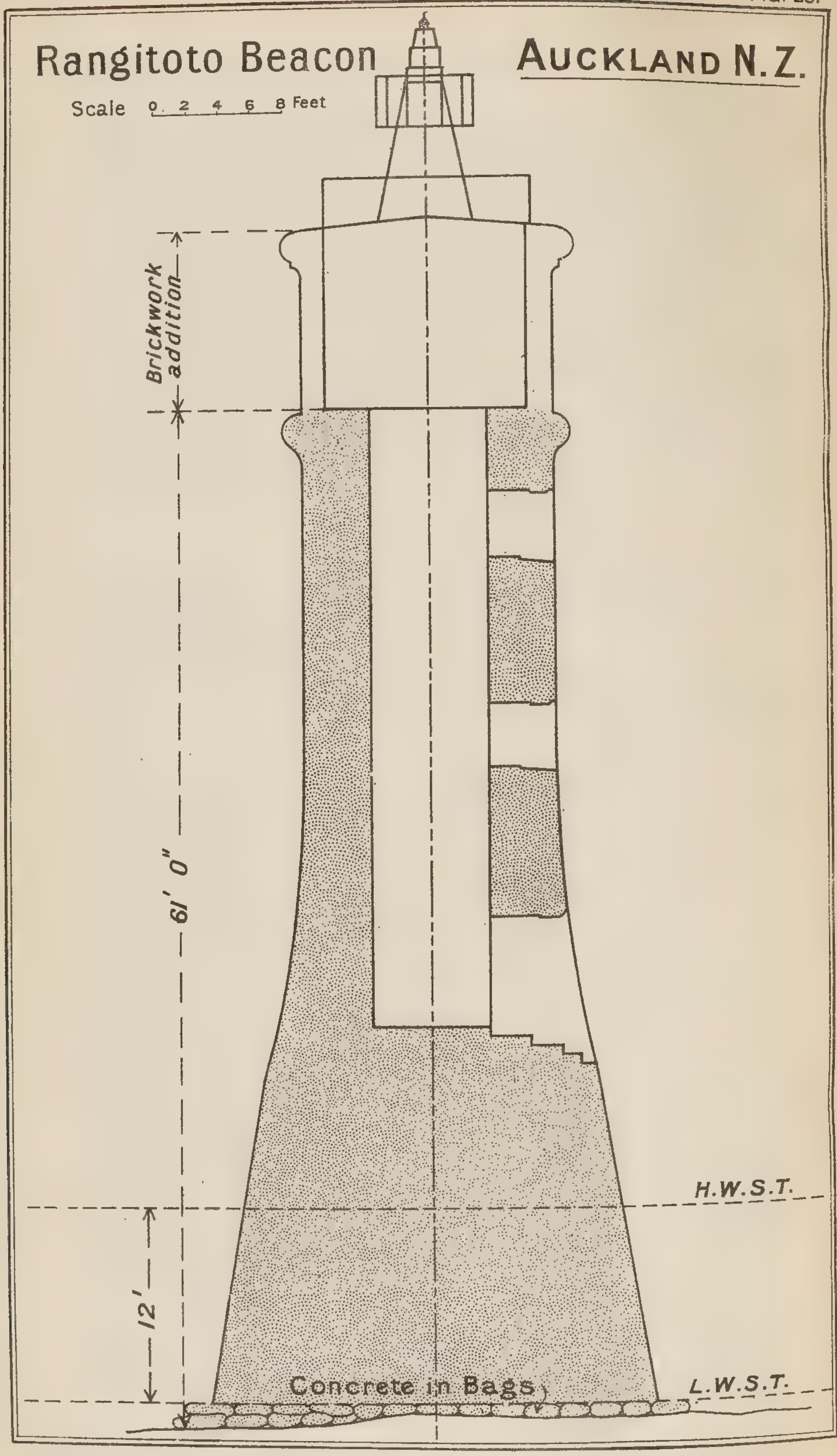
Year.	Structure.	Built of	Area in sq. yds. of rein. concrete.	Lineal feet of rein. concrete or mass concrete.
1904	Breastwork .	Main, sheet and tie piles in reinforced concrete.	—	242 R.C.
1904-6	Wharf . . .	Open pilework in reinforced concrete.	28,400	—
1906-13	Wharves . .	Do., do.	39,750	—
1908	2 Walls . .	Mass concrete	—	2,634 mass
1908	2 Wharves . .	Open pilework in reinforced concrete.	7,777	—
1906-9	2 Wharves . .	Do., do.	4,785	—
1909-11	Wharf . . .	Mass concrete and open pilework in reinforced concrete.	4,033	1,166 mass
1915-16	Quay . . .	Open pilework in reinforced concrete.	7,104	—
1916-17	Wharf . . .	Do., do.	21,422	—

Auckland Dry Dock.—Concrete was used here in sea-water in 1878 up to H.W. mark for the floor and side walls, and for setting the blue stone with which the dock was lined.

This dock was demolished in September–December 1915—after 37 years. The concrete was found to be in excellent condition, and had not become deteriorated in any way. Its composition, as given in the original specification, was:—

"The invert to the body of the dock, the head and the entrance to be bedded, flushed up, and grouted in best Portland cement, ground scoria ash, measure and measure of each. Altar stones and all stones in faces of walls to top of broad altar (= H.W.S.T.) to be bedded, flushed up, and

FIG. 28.


Rangitoto Beacon
AUCKLAND N.Z.
Scale 0 2 4 6 8 Feet
Brickwork addition
61' 0"
12'
H.W.S.T.
L.W.S.T.
Concrete in Bags

grouted in cement; the remainder of the stonework to be bedded, flushed up, and grouted with mortar and grout."

Calliope Dry Dock.—Concrete was next used in the construction of Calliope Dock in the year 1886. The structure is as sound to-day as when first made. The floor of the dock was re-surfaced about 1901, but this was only on account of damage by weights dropped on to and breaking it. No defect of any kind due to sea action has been observed after 31 years. In cutting away the lower altars, in 1907, to give increased width for shipping, the concrete was found to be very hard and clean, and of excellent quality. The composition was:—

Concrete, using English cement, contained one part by measure Portland cement to five parts by measure of clean shingle. The aggregates consisted of one measure of broken scoria, the balance of red scoria ash, or alternatively, altogether with broken scoria and sand as directed.

The concrete facing, 3 inches thick, was made of one part Portland cement to two parts of pea gravel; rubble concrete consisted of basaltic rock stones, 3 inches apart. The original drawings show this to be "rubble concrete, six to one," and it was found in cutting away altars to be shingle concrete with large bluestone plums.

Rangitoto Beacon.—Built in 1887 of mass concrete with stone plums.

Original height 61 feet from base; diameter 15 feet increasing to 27 feet at base. This beacon stands on a reef exposed to heavy seas. From reef to L.W. (about 1 foot) was built of concrete in bags, specified as follows:—

1 part by measure of Portland cement
1 part ,, ,, ,, sand
2 parts ,, ,, ,, coarse clean shingle
2 parts ,, ,, ,, 2-inch broken metal

The remainder of the structure from L.W.S.T. upwards was composed of:—

1 part by measure of Portland cement
1 part ,, ,, ,, sand
2 parts ,, ,, ,, coarse shingle
3 parts ,, ,, ,, 2-inch broken metal

Nothing has been spent to date on the upkeep of the beacon, with the exception of putting half a dozen extra bags of concrete in the base on the reef, about 1906.

Only the lowest 12 feet of the beacon stands in water at H.W.S.T., but all is subject to heavy spray and driving winds, see Fig. 28.

Mass concrete has also been used in the form of retaining walls supporting earth filling.

A wall 784 feet long was substituted in 1908 for a timber breastwork that had twice been renewed. The concrete for this wall was lowered in skips through quiet water inside timber framing. The specification for this concrete was as under:—

Cement, N.Z. or English, to British Specification. Concrete below a level of 2 feet above L.W.S.T., 1 cement, 2 sand, 3 shingle and broken bluestone. From above level to cope, 1 cement, 2 sand, 4 shingle, with

large bluestone plums 9 inches apart—stones 9 inches to 15 inches cube. The wall has not shown deterioration of any kind, and nothing has been spent on maintenance in 9 years see, Fig. 29.

A wall 1,850 feet long was built in 1908. This was all constructed in the dry, as the foundation in the worst case was only 8 feet below L.W.S.T. A rough coffer-dam was formed, the water was pumped out at L.W. and the concrete was deposited on the bare sandstone.

The specification of this concrete was :—cement to be English or local, equal to British Specification: 1 cement, 3 sand, 2 shingle, 3 broken stone, large plums of bluestone to be used, placed not nearer together than 9 inches. This wall shows no sign of deterioration, and nothing has been spent to date (9 years) upon maintenance.

A concrete wall 1,166 feet long, built 1911, was deposited through water to 2 feet above L.W.S.T. by skips within timber framework.

The mixtures used for this wall were :—

Base to 2 feet above L.W.S.T., cement, English or local to British Specification. Concrete—1 cement, 2 sand, 2 shingle, 2 broken stone; upper part to cope—1 cement, 3 sand, 2 shingle, 3 broken stone with large plums as in previous walls.

Concrete caissons, weighing about 70 tons, were substituted in 1912 for a timber breastwork which had collapsed after ten years, owing to the lower ends of the totara timber ties having been destroyed by limnoria and chelura. The caissons were 1 cement to 6 of shingle and sand, and they were placed upon a rubble stone base. They were filled with common concrete, and nothing has been spent on their maintenance since construction. There have been no failures attributable to faulty cement. The local cements are satisfactory and fulfil all requirements of the British Standard Specification.

Reinforced Concrete.—The materials used are :

Cement to British Standard Specification.

Shingle ; proportion of voids to bulk after screening and ramming not to exceed 25 per cent. Weight after driving off moisture about 108 lbs. per cubic foot. Weight containing moisture, as taken from natural beaches 114 to 118 lbs.—some 130 lbs. After passing through sieves, the residue on a screen 5 by 5 mesh to 1 square inch to be not less than 45 per cent. or more than 60 per cent. by weight. Then sieving what has passed the 5 by 5 sieve, the residue on screen 12 by 12 to 1 square inch to be not less than 20 per cent. or more than 30 per cent. by weight.

The quantity left on the 5 by 5 sieve represents the coarser stone ; the quantity left on the 12 by 12 sieve represents the finer stone ; and what passes the 12 by 12 represents the sand.

The largest size of shingle not to exceed screen of 1-inch mesh. All shingle has been the natural combination of shingle and sand taken from local beaches. This is mostly perfectly clean and free from extraneous matter.

Concrete Mixtures.—For piles and all members below H.W.S.T. :—

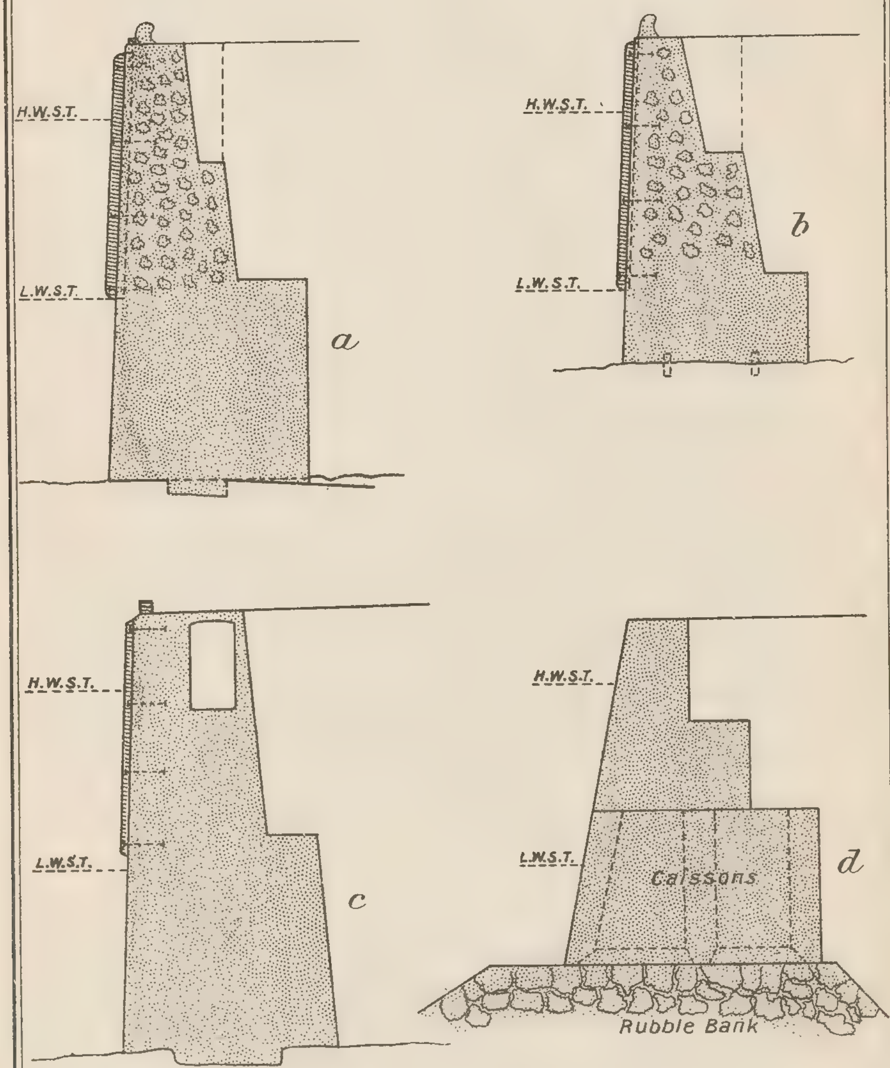
1 part by volume of cement.

$3\frac{1}{2}$ parts by volume of shingle and sand.

FIG. 29.

AUCKLAND HARBOUR.

Concrete Walling.



Concrete Walls mentioned in report

Scale : 0 2 4 6 8 Feet

For girders, beams, and decking above H.W.S.T.:—

1 part by volume of cement.
4 parts by volume of shingle and sand.

Defects.—The defects due to sea-water noted in the earlier works have been small and have been attributable to:—

(*a*) Bars being displaced in course of construction being too near the surface of concrete, causing signs of rust and occasional bursting of concrete along a length of the bar, due to rust scale, not being properly cleaned off before concreting.

(*b*) Too thin a covering of concrete over ferrules that were originally used to lengthen the main pile bars when these were found to be a few feet short, after piles had been driven. The ferrules were found to hold moisture from the concrete and to reduce the thickness of the concrete covering where they occurred. This system of ferrules was eventually discarded. Where ferrules had been used the difficulty was overcome by cutting out, boxing up, and putting on a concrete covering of from $1\frac{3}{4}$ inches to 2 inches. No further sign of defect has arisen.

(*c*) Other signs of rust on the surface arose from stray nails left in the timber framework which appeared in the surface of the concrete when stripped, and fragments of iron mixed with the shingle used for the concrete.

These defects have since been obviated by placing under every bar small concrete blocks about 2 inches by 1 inch by the thickness of covering required between the bar and the surface. In decking this is $\frac{5}{8}$ inch and in girders and beams 2 inches.

Defects in Decking.—The only defects are those mentioned above. No expansion-joints are provided and cracks occur at varying intervals. On the commercial wharves the working surface is covered by asphalt so that all cracks are protected; and on passenger jetties, where there is no asphalt, the expansion cracks have not caused any difficulty.

Temperatures observed above and below wharf decking at 1 p.m. on March 2nd, 1917 (a typical summer day) were:—

In sun at deck surface	114° F.
In shade at deck surface . . .	70° F.
Underneath decking	70° F.

Piling and Bracing in Tideway and below Low Water.—The piles are made ashore and are allowed to indurate for about three months before being driven. No defects whatever have been noticeable in the piles except where they were lengthened at about H.W.S.T. as already described. They are no longer lengthened *in situ*, but are moulded full to length, and if necessary are cut down to exact length.

Diagonal bracings and horizontal walings in the tideway are moulded *in situ*, the only defects observable in the original work were as previously described. The only work below L.W. is the lower part of the piles. These have been carefully examined by a diver from time to time and no defect has been discovered.

Since the earlier work of 1906 and 1907 the concrete covering of all

o 2

bars of piles has been increased to 2 inches. No further defects have occurred.

Preservative Effect of Various Thicknesses and Strengths of Concrete Coating on Embedded Steel.—Four to one cement concrete has been found in nearly all cases to be quite satisfactory except where otherwise described, but latterly all reinforced concrete work in the tideway has been made $3\frac{1}{2}$ to 1, and the concrete covering of bars, except decking bars, has been made $1\frac{3}{4}$ inches to 2 inches.

Junctions between Members below High-Water Mark. — Constant observation of these junctions has failed to reveal any defect. When work is ready for it, piles are cut through for junction with walings and braces. The steelwork of members is next threaded through the pile and is all boxed up; the concrete is then immediately poured into the moulds. It is thoroughly well rammed in position and boxed over before the rising tide covers it. Satisfactory results have been achieved in this way.

Waterproofing.—None of the compositions offered have been used, nor do they appear to be necessary here.

Some experiments were made by exposing lengths of pile bars just below H.W.S.T. and covering them with various kinds of paint, tar, and cement washes. The concrete of some piles was also painted with various paints, but none were lasting, and in 12 to 18 months they had disappeared.

Damage by Bumping of Ships.—The outside piles of wharves were originally protected by timber fenders extending to L.W.S.T., bolted directly on to the concrete pile face or packed out where there were single front piles. Occasionally a ship falling heavily against these fenders would flake off a spawl of concrete on one or both sides of the front pile at the level where it struck. This would be about the size of one's hand, tapering from a thickness of 1 inch to *nil.* This refers particularly to local coasting vessels, which have beltings around their hulls, but the total of all such damage has been small.

Subsequently the solid fenders were packed off the face of the pile about 2 inches to allow of some spring between deck level and low-water, and this acted well. Finally spring fender piles of full length were substituted in some ocean berths for the previous fenders to L.W. only, and no damage has since occurred, see Fig. 30.

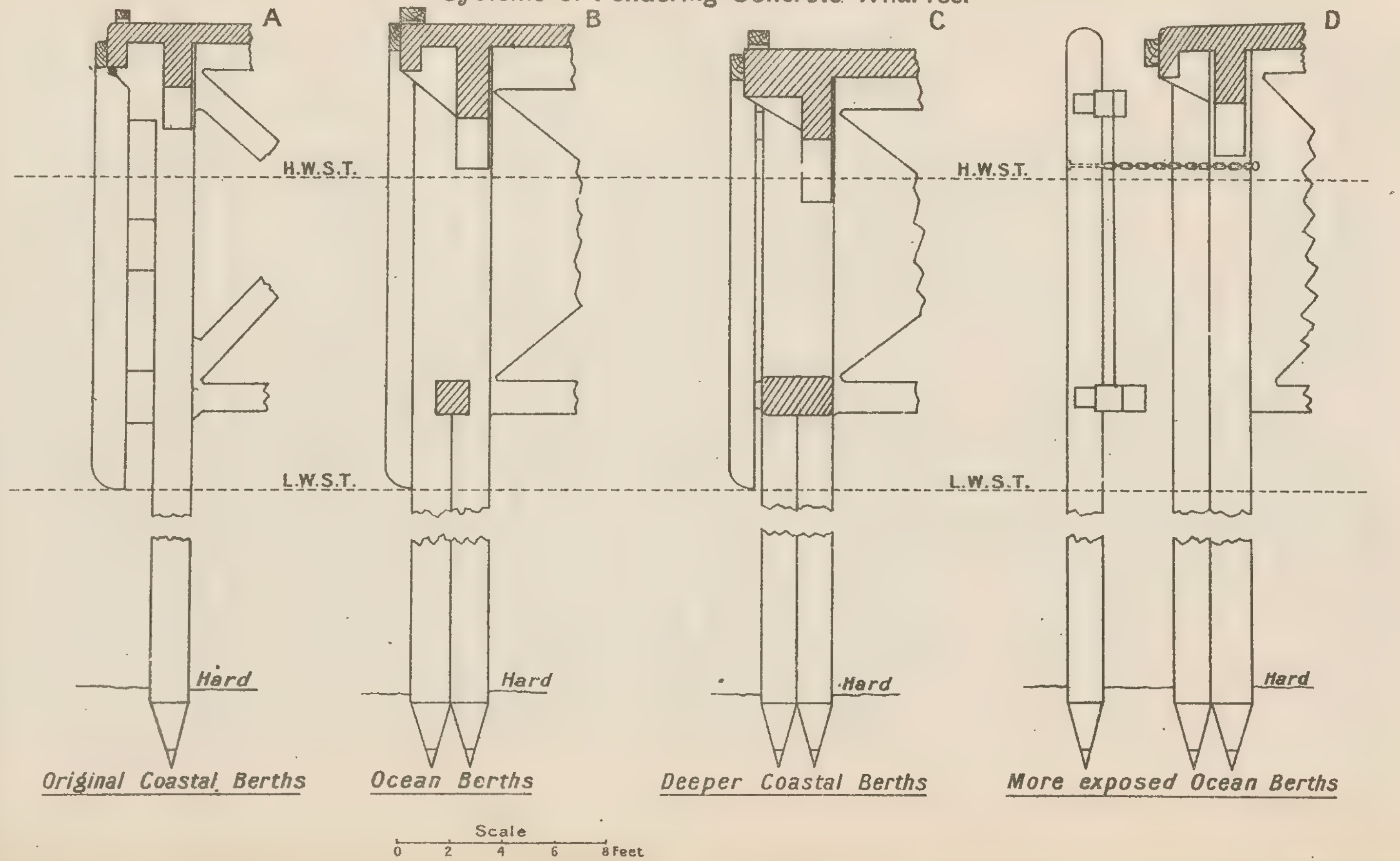
In the original berths for smaller shipping only, single piles were used in the front row, with single diagonal bracing behind and a fixed timber fender in front. One or two accidents occurred, where vessels colliding with the wharves caused the single front pile to be cracked. All recent works, whether for large or small shipping, now have double piles in the face row, which are cross-braced behind and the quadrant at the back of the front piles is filled solid. In both cases, where these are protected by either solid fenders or spring pile fenders of timber, no damage of any kind has been done.

Maintenance.—The cost of maintenance of the reinforced concrete of wharves averages under one halfpenny per square yard per annum over a period of 8 years, covering repairs to all concrete, but based on surface

FIG. 30.

AUCKLAND HARBOUR.

Systems of Fendering Concrete Wharves.



area only. The cost for the timber wharves averaged $11\frac{1}{2}d.$ per square yard per annum over the same period.

Structures of Steel and Iron.

The only structures of steel or iron in the sea-water of this harbour have been :

- (*a*) Caisson and pumps at Calliope Dry Dock.
- (*b*) ,, ,, Auckland Dry Dock.
- (*c*) The steel cylinder foundation of sheer legs at Calliope Dock.
- (*d*) Steel pontoons.
- (*e*) Bean Rock Light: Cast-iron pillars and wrought-iron tie bars.
- (*f*) Members of bridges for landing-stages (these are always just above water).

(*a*) *Calliope Dock Caisson.*—The caisson, built of iron in 1888, was docked for examination in 1913, and was found after 25 years to be generally in good condition. The only plates renewed were those on the inner or dry dock side, four on the northern end and one on the southern end. These renewals were specified to be of British Standard structural steel for shipbuilding.

The strip of plates renewed on the inside were about 2 feet above low-water, and were pitted in places to about 40 per cent of their thickness, viz. from $\frac{3}{8}$ inch to $\frac{5}{8}$ inch. Those at the northern end were between high- and low-water, that at the southern end was from low-water line to about 9 feet below. Many rivets were replaced. Angle-irons holding facing-pieces were completely corroded to a knife-edge from mean tide to 8 feet below.

The whole of the timber facing-pieces were renewed throughout with heart of totara in 1913. Greenheart was originally specified for facing-pieces, but this had evidently been mostly replaced by totara, as lengths of greenheart rubbing-pieces still left at the top were found to be badly wormed at their lower ends, which were at about half tide. Two bearing timbers along the bottom of the caisson were of greenheart, but being always in the mud except when floated had only been attacked by small teredo on the outside surface to a depth of about $\frac{3}{16}$ inch in patches.

The caisson was constructed of wrought-iron plates of either Crown or B.B. Staffordshire brands. Floor plates were specified to be $\frac{7}{8}$ inch, sides and ends to the height of 10 feet to be $\frac{3}{4}$ inch, and $\frac{5}{8}$ inch above that level.

The plunger pumps were replaced at the same time (1913). The cast-iron water cylinders had been giving trouble for some time, owing to the softening of the cast iron, which allowed bolts to work loose. When taken out the cast-iron was found to be soft, and could be cut with a knife.

(*b*) *Auckland Dry Dock Caisson.*—This caisson, built in 1878 of best Staffordshire iron, was docked for repairs in October, 1886, and was found after 8 years to need the following renewals :—

Timber facings at ends and sills and rubbing-pieces on bottom removed.

Bottom and end-plates and first three rows of side plates on outside and bottom rows on dry dock side of caisson damaged. These were replaced by $\frac{1}{2}$ inch B.B. iron plates. The iron sluice valve spindles were replaced by gun metal. All timbers were replaced by new heart of totara.

All ironwork was finally painted with two coats of red lead mixed as follows: red lead, 1 cwt.; white lead, $\frac{1}{4}$ cwt.; boiled oil, $1\frac{1}{2}$ gallon; raw oil, $1\frac{1}{2}$ gallon; turpentine, 1 gallon.

The bottom of the caisson inside was covered with $3\frac{1}{2}$ inches of cement mortar, mixed in proportion of 1 part by measure sharp sand, 1 part by measure cement.

In January, 1911, this caisson was again docked, all timbers were replaced by selected heart of totara; three rows of plates from H.W.S.T. to about half tide and the bottom row of plates about 2 feet below L.W.S.T. were replaced by mild steel plates on the side towards the dry dock, and the two lower plates on the western end were replaced by mild steel plates. Practically all rivetting was renewed. The bottom plates were $\frac{1}{2}$ inch and the upper plates $\frac{3}{8}$ inch to $\frac{5}{16}$ inch.

All plates were chipped inside and out, the interior received three coats of cement wash. The outside was painted three coats. The concrete on each interior deck of caisson was renewed. The three upper decks had $1\frac{1}{2}$ inch of concrete and the bottom $3\frac{1}{2}$ inches of concrete.

(*c*) *Calliope Dock Cylinder for Sheer Legs Foundations.*—These cylinders were sunk in 1907. Their tops were connected at about high-water level by steel lattice girders. These were painted with two coats of red oxide, but as they showed rust in 18 months or 2 years they were cleaned down and washed over with neat cement. This is done about every 2 years, and appears to afford sufficient protection. The cylinders and girders were of steel, built to Admiralty Specification in England.

(*d*) *Pontoons.*—The steel pontoon at Birkenhead vehicular landing-stage was launched in 1910, and docked for repairs in October, 1916, it had been painted with one coat red oxide and three coats coal-tar. After 6 years and 5 months the plates were generally in good condition, with very little pitting. In many places there was none, and in others the pitting was only slight.

It was again coated with three coats of hot coal-tar with a little pitch in it. The surface below water-level had become coated with a blanket of oysters, mussels, and seaweed to a thickness of 8 inches. Some fronds of seaweed were 3 feet long.

The steel specified was open hearth, ultimate strength from 60,000 to 70,000 lb. per square inch, elongation not less than 22 per cent. in 8 inches. Rivets of soft rivet steel.

The steel pontoon at Hobson Vehicular Landing Stage, launched 1913, has not yet been docked. It was painted with three coats red lead in oil, and just before launching with one coat coal tar, and appears to be in thoroughly good condition at the present time. The steel specified was to British Standard Specification for structural steel for shipbuilding. The interiors are washed with three coats of neat cement and are efficiently ventilated. This is found to be very necessary, and keeps them quite dry.

The steel hulks of floating plant, such as dredgers, which are annually

docked, cleaned, and painted, are not referred to in this report. The oldest of these—now 32 years in use—has never had any new plates.

(*e*) *Bean Rock Lighthouse.*—Built about 1870. The original cast-iron columns and wrought-iron ties are still in use. The only damage has been caused by drifting logs, which smashed the cast iron. The tiebars, though painted, show considerable incrustation from rust.

(*f*) *Members of Steel Bridge built in* 1904.—Some flat bar tension members of a steel bridge joining a pontoon landing stage with the shore, though carefully painted, were found to commence pitting in small circular patches. This bridge is always just above water level. Adjacent members of rolled joists, angles, and plates remain perfectly sound. Notwithstanding burning out, and cleaning down with a file to bright steel, none of the paints, tars, or bitumen tried appeared to be effective in arresting this local and rapid corrosion until recently, when the difficulty seems to have stopped, and the corrosion has gone as far as it seems likely to do. As none of the members of other bridges have shown signs of similar corrosion, this damage is attributed to some defect in the chemical constitution of the steel.

Experimental Work.—As timber is likely to be entirely replaced by concrete in some form, and as experiments have already been made on so many local and imported woods, it does not seem likely that more can be usefully done in that direction here; but the following timber specimens have been prepared for experiment. There are four of each kind—each is 4 feet by 4 inches by 4 inches.

One specimen will be kept for the Committee.

One specimen untreated . . One specimen treated with creosote One specimen treated with vaseline and then charred . . .	Will be placed in sea-water at low water level, half being always submerged and half being bare at normal low water.

LIST OF TIMBERS.

Local Name.	Where grown.	Botanical Name.
Kauri	New Zealand	*Agathis australis.*
Rimu	,, ,,	*Dacrydium cupressium.*
Totara	,, ,,	*Podocarpus totara.*
Mangeao	,, ,,	*Litsea calicaris.*
Manuka (White)	,, ,,	*Leptospermum ericoides.*
,, (Red)	,, ,,	,, *scoparium.*
Maire (Black)	,, ,,	*Eugenia maire.*
Matai	,, ,,	*Podocarpus spicatus.*
Kahikatea	,, ,,	,, *dacrydioides.*
Taraire	,, ,,	*Beilschmiedia taraire.*
Blue Gum	Tasmania	*Eucalyptus globulus,*
Stringy Bark	,,	,, *capitellata.*
Ironbark	N.S.W.	,, *paniculata.*
Turpentine	,,	*Syncarpia laurifolia.*
Oregon	U.S.A.	*Pseudotsuga douglasii.*

Several specimens of various timbers treated, with (a) Jodelite (b) Vaseline and then charred, have been down for nearly 3 years and are still under water. They will be reported upon after completion of the third year in April, 1917.

"P. & B." felting has been tried on ironbark fender piles, but it soon lost its nature or was abraided by shipping and would be ineffective.

"Powellising" of some timbers was tried, and while this temporarily extended the immunity of the timber as compared with untreated specimens, it did not continue and they rapidly deteriorated.

APPENDIX "A."

REPORT MADE ON 29th MARCH, 1876, BY THE ENGINEER TO THE AUCKLAND HARBOUR BOARD ON TIMBERS USED IN THE CONSTRUCTION OF THE AUCKLAND WHARVES, WITH A VIEW TO COMPARING THEM WITH JARRAH AND OTHER AUSTRALIAN TIMBERS.

The following are excerpts from the report:—Remedies for the ravages of the teredo and limnoria have been tried, but none have been permanent in all situations. Creosote failed.

On the 3rd July, 1874, jarrah used for the Mangere Bridge at Onehunga on the Manukau Harbour, about 6 miles south of the city of Auckland, was obtained for testing at Auckland. This had been specially selected by the contractor, who had visited Western Australia for that purpose. After 21 months submersion at Auckland it was found that the teredo was doing damage.

Jarrah piles were used for the old Mangere Bridge and were driven in 1874. They were badly damaged by teredo in 1876, and were entirely replaced by totara in 1880. Two turpentine piles were driven at Auckland in June, 1872, and $2\frac{1}{2}$ years afterwards it was found that the teredo had been at work for some time upon them. Swamp gum piles imported from Tasmania in 1865 for Queen's wharf were attacked and several of them were completely riddled in 18 months. Australian ironbark is at once attacked and is destroyed most rapidly, see Plates XXV. and XXVI.

The late Captain Ferguson, Harbourmaster for the Government of Victoria, stated that stringy bark was destroyed in 8 years, blue gum in 5 to 8 years, white gum in 6 to 8 years, blackwood eaten right through in the same time, ironbark attacked and rapidly destroyed. This occurred also in Sydney and on the Clarence and Macleay rivers.

From the above it was concluded that Australia possessed no timber able to resist the ravages of marine borers for more than 8 to 10 years.

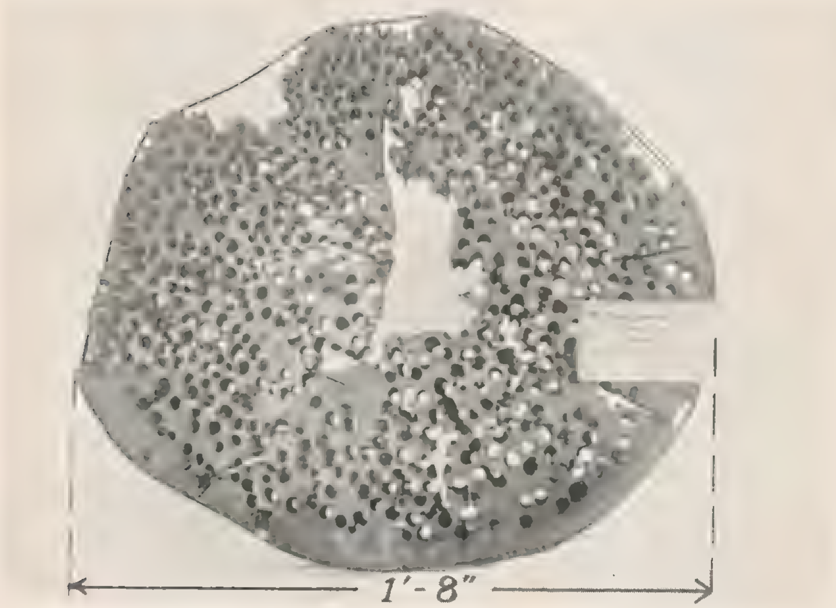
The report continues:—

In rebuilding Queen's Wharf, Auckland, 300 totara piles were drawn, and with few exceptions teredo had failed to penetrate the heartwood.

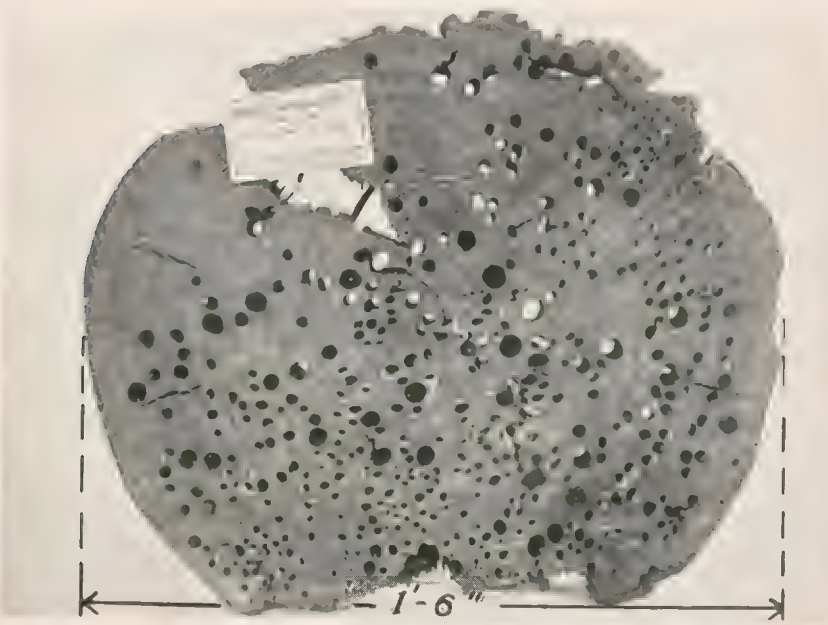
Totara piles driven in Onehunga wharf in 1865 were still sound in 1876 (and a number of these are still in use to-day—1917).

No timber in the colonies was considered to equal totara for resisting sea-worms. Notwithstanding this, sheathing of copper or Muntz metal was needed, sheathing to extend 3 feet into mud and to be carried up to high-water mark. Though adding to cost, this prolongs the life of the structure for many years.

AUCKLAND, NEW ZEALAND.

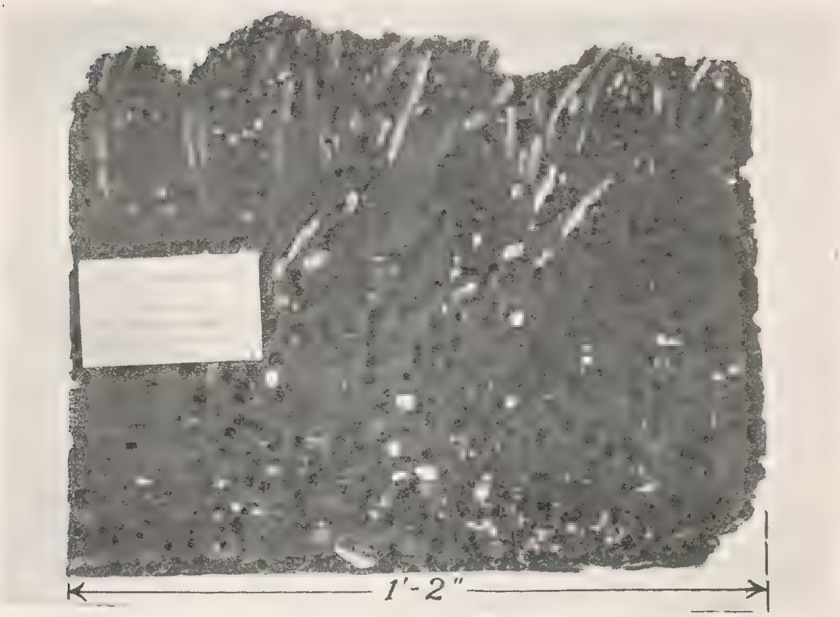


Section of Pile of Blue Gum (*Eucalyptus globulus*) from Old Queen Street Wharf, after about 27 years' immersion.

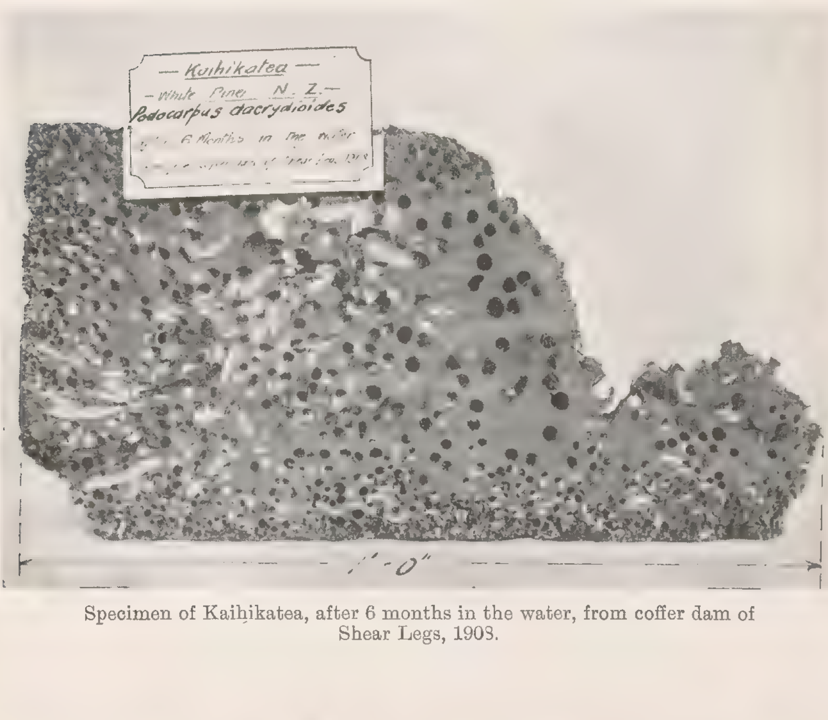


Section of Pile of Blackbutt (*E. pilularis*) from Old Queen Street Wharf, in use about 27 years.

AUCKLAND, NEW ZEALAND.



Specimen of Jarrah (*Eucalyptus marginata*) from Birkenhead Wharf, after being in use about 3 years.



Specimen of Kaihikatea, after 6 months in the water, from coffer dam of Shear Legs, 1908.

All totara piles should be procured as large as possible, say not less than 15 inches to 17 inches square head, cut from fully grown trees, well axed square and smooth and free from sap.

Walings and braces should be of heart timber—the heaviest timber should be selected.

Hokianga totara weighs from 60 to 62 lb. per cubic foot.

Whangarei totara weighs from 60 to 63 lb. per cubic foot.

Puhoi totara weighs from 66 to 68 lb. per cubic foot.

All weights are taken from newly fallen timbers.

The totara from above localities is considered best for piles, being heaviest and with less sapwood than is usually found on the totara grown at other places.

APPENDIX "B."

EXCERPTS FROM LETTERS FROM ENGINEER TO THE COUNTY OF HOBSON, DARGAVILLE, NEW ZEALAND.

The Tangahai Wharf was built in 1911 of turpentine, totara and ironbark piles. The totara and turpentine are still quite sound, but the ironbark is completely riddled. Tangahai Wharf is 24 miles from the Kaipara heads. The specimen sent was taken from low water where the pile was broken right off.

The temperature of the water on 12th March, 1917, was 71° F. The degree of salinity varies with the quantity of water coming down the river Wairoa, but water at Tangahai is never pure sea-water, and at times there is very little salt in it. There is always a large amount of sediment in the water at this wharf, which at no time would be clear. Salt-water fish are caught 7 miles above this point, while mangroves extend to 10 miles above the wharf.

Seven miles above Tangahai, kauri piles have stood well for many years; even kahikatea timber, if covered only at high water, lasts well in this river. This is probably due to the skin of fine mud which coats them.

A barge built of kauri, and used for about 5 years in the lower part of the harbour, was absolutely riddled with teredo, but totara sheathing over kauri has proved quite effective.

APPENDIX "C."

ONEHUNGA WHARF, MANAKAU HARBOUR.

This wharf, built in sections during the years 1877, 1887 and 1891, was constructed of totara piles.

A report in 1913 concerning their condition showed that

Of the 1877 piles 21½ per cent. needed renewal,

Of the 1887 piles 16½ per cent. needed renewal,

Of the 1891 piles 15 per cent. needed renewal.

A note adds:—"A number of piles are considerably eaten between low and high water but have some life left in them yet."

It is worthy of note that with these few exceptions the piles are in good condition. Probably some of the piles in the above areas had been

renewed from time to time by the Railway Department before the Auckland Harbour Board took the wharf over from the Government in 1913, but the Board has no record of this.

On examination on April 11th, 1917, the limnoria appeared to be doing the greater damage, and there was no outward sign of teredo, but the total damage appeared to be less than in the Auckland Harbour.

APPENDIX "D."

TIMBERS USED IN AUCKLAND HARBOUR.

TABLE OF WEIGHTS.

Local Name.	Where grown.	Botanical Name.	Weight per cubic foot. Wet.	Dry.
Kauri	New Zealand	*Agathis australis*	42	37
Rimu	,, ,,	*Dacrydium cupressium.*	68	38
Totara	,, ,,	*Podocarpus totara*	68	34
Matai	,, ,,	,, *spicatus*	54	41
Kahikatea	,, ,,	,, *dacrydioides*	67	31
Jarrah	Western Australia	*Eucalyptus marginata*	61	50
Blue Gum	Tasmania	,, *globulus*	64	51
Stringy Bark	,,	,, *capitellata*	64	59
Ironbark	New South Wales	,, *paniculata*	76	70
Turpentine	,, ,,	*Syncarpia laurifolia*	69	62
Greenheart	British Guiana	*Nectandria rodioei*	73	65
Oregon Pine	U.S.A.	*Pseudotsuga douglasii*	42	26

TESTS OF TIMBER.

Tests were made of 15 sets of timbers, each set consisting of 4 pieces. (See p. 199.)

(*a*) One in its natural state.

(*b*) One treated by Cunningham's carbo-teredo process.

(*c*) One treated by two coats crude creosote, painted on only.

(*d*) One sample of each has been kept dry and untreated for reference.

NOTE: Only two samples of mangeao and white manuka were available. One of each of these was left in its natural state and one of each was treated with two coats of crude creosote (none being treated by Cunningham's process, and none kept for reference.)

All the above 15 sets except (*d*) were placed under western end of Sheer Legs Wharf, Calliope Dock, on 13th April, 1917. On 21st May, 1917, there were added to the above 3 pieces of black maire, one untreated, one carbo-teredo process, and one with two coats of crude creosote.

On 15th April, 1918, we examined the above timbers. These had been down exactly one year, having been placed there on 13th April, 1917. On a careful examination of the exteriors of all these specimens, and by chipping corners of some of the untreated ones, it was seen that they were as yet scarcely touched. The untreated Oregon and rimu showed that small teredo were just touching their lower ends, which had always been at a level of about L.W.S.T.

Small patches of the surfaces of some of the other specimens showed

that the limnoria were beginning to work, but not badly as yet. The kahikatea showed limnoria at its lower end. There was a growth of weeds, small oysters, and jelly fish, about 1 inch thick, on the lower end of these timbers. The surfaces of all specimens were fairly evenly covered with small barnacles.

Section of Trunk of Untreated Pohutukawa (Metrosideros tomentosa).—This is a very heavy timber, with interlacing fibre, used for keel blocks for dry docks, knees of timber vessels, and stems of small vessels. A specimen was placed about 3 feet above L.W.S.T. under west end of Sheer Legs Wharf, 21st May, 1917. The weight in green state before being put under wharf was 83·5 lb. per cubic foot.

The above was inspected on 15th April, 1918, and three pieces were cut off for investigation. Generally speaking, it was thoroughly sound except for a few small teredo bores on the extreme edges.

Specimens treated by Cunningham's Carbo-Teredo Process.—(This consists of charring with a blow lamp and painting with two coats of vaseline.) Placed in sea-water under Queen's Wharf, 17th July, 1916. Removed to west end of Calliope Dock, 21st May, 1917. Report on 23rd May, 1917, after 10 months :—

"The untreated pieces much eaten by limnoria and thickly covered with barnacles on upper ends. Pieces treated by Cunningham's process seemed quite sound and had mussels and seaweed fairly thick on them."

NOTE: These specimens were eight in number, each 3 inches by 3 inches and about 4 feet long, of kauri, rimu, kahikatea, and Oregon pine; one set of 4 treated and one set of 4 untreated.

On 15th April, 1918, the specimens mentioned above were inspected. These were put in sea-water about 2 feet to 5 feet above L.W.S.T. on 17th July, 1916. The untreated pieces were practically completely spongified, riddled with teredo, and half of one of them completely eaten away and lost. The others would hardly bear touching, being practically held together by the lime linings of teredo bore holes. The pieces treated by the Cunningham process were then cut in places with a sharp axe.

The kahikatea, rimu, and kauri appeared to be entirely untouched by teredo or limnoria, but the Oregon pine was getting riddled, where it was cut at the top, middle, and bottom of specimen, with teredo holes from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch diameter.

It is clear, however, from the comparison of the treated and untreated specimens that Cunningham's carbo-teredo process has had a distinct preservative effect up to the present (a period of 21 months), on the kahikatea, kauri, and rimu, which otherwise would certainly have been riddled.

Specimens treated with "Jodelite."—Specimens were submerged 15th April, 1914, at Calliope Dock. Specimens were of jarrah (No. 1), kauri (No. 2), and kahikatea (No. 3). On examination, 9th March, 1915, all treated pieces were found to be sound, also the untreated jarrah; but the untreated kauri is being attacked by the *Chelura terebrans*, and the untreated kahikatea by the teredo as well.

On 17th April, 1917, the specimens were taken up and cut open; the kauri had been already entirely destroyed.

PORT LYTTELTON, N.Z.

By M. F. G. WILSON, M.Inst.C.E., Member of the Special Committee.

Reference is made in the circular letter to corresponding Members to the nature of sea-water in which the structures have been erected—whether affected by sewage, etc. The writer came across a rather curious instance some years ago at Port Lyttelton, New Zealand, which, perhaps, may be of interest.

Australian ironbark timber was largely used for piles for jetties and wharves, and some piles which had been in the water 37 years were examined and were found to be perfectly sound. In the case of one broken pile, slight indications of teredo were observable. In a recent letter to the writer, the engineer to the board says:—"No. 6 jetty is now rebuilt parallel to No. 7, stiffened with raking piles so that there are no bracings or other fastenings under water. By avoiding these I estimate the life of good ironbark piles at 100 years at least." The 100 years may prove too long, but there is no doubt whatever that at Port Lyttelton ironbark is extraordinarily durable, whereas at Wellington, not many miles north, the life of the same timber amounts to only a very few years, and it is the same at Auckland and other ports. Locally the immunity of ironbark was attributed to volcanic dust in the water which prevented the teredo from thriving, but the writer is not aware that this has been proved.

OTAGO HARBOUR, N.Z.

By J. BLAIR MASON, M.Inst.C.E., Consulting Engineer.

Otago Harbour is a sea inlet, about 14 miles in length, with an average of about 3 miles in width. The bed of the harbour and the banks, which uncover extensively at low water, consist of a bluish mud, with sand patches at intervals. The quantity of the inflow of fresh water is very limited. As the water of the harbour is generally shallow, the fine mud off the banks becomes raised in suspension in windy weather, especially so in the upper portion of the harbour, where the discoloration of the water from this cause is very marked. Four years ago the greater portion of the sewage of Dunedin City was discharged into the harbour, and the suspended sewage and natural mud could then usually be found extending throughout the area occupied by the harbour works and wharfage at Dunedin.

These physical conditions may account for the absence in Otago harbour of the teredo, whose destructive effects can be noted in the piles of structures at the harbours on either side. Neither does the limnoria find these waters healthy, with the consequence that the heart wood of most of the local timbers, of which the old original jetties were constructed, has stood well. It was found long ago, in the absence of New Zealand timbers possessing the necessary strength, that the Australian hardwoods (*Eucalypti*) were suitable for wharf construction; and piles of ironbark driven in this harbour 40 years ago are still in good preservation. In fact, this variety of hardwood is all that can be desired for pile structures in

these waters, and it is only owing to its increased cost that the Board have been compelled to use ferro-concrete.

In 1906, plans were prepared for a wharf in ferro-concrete at Dunedin, of a monolithic character, which was completed in 1908. The piles were octagonal, $14\frac{1}{2}$ inches from face to face, and up to 60 feet in length. The concrete used was a 1—2—4 mixture of broken bluestone and clean quartz sand, with a carefully tested Portland cement. Great care was taken in the gauging of the materials and their proper mixing and ramming into the forms, which were in most cases lined with unbleached calico so as to prevent any oozing of the cement. A careful inspection of the work to-day shows no apparent deterioration after a life of 11 years.

WELLINGTON HARBOUR, N.Z.

By JAS. MARCHBANKS, M.Inst.C.E., Engineer to the Harbour Board.

The wharves and quays in Wellington Harbour, see plan, Fig. 31, extend slightly over 19,100 lineal feet, of which length about 16,850 feet are built of timber and 2,250 feet are constructed with reinforced concrete.

Piles.—In all of the timber wharves the piles are protected from below ground level to 6 inches above H.W.O.S.T. by sheathing, which is laid on ship's felt, the pile having been first coated with chenam. The covering affords a complete protection to the timber against the teredo, limnoria, etc., so long as it remains intact.

A native timber that has been largely used for piles is totara, *Podocarpus totara*, which at one time could be produced in lengths up to 50 feet by 16 inches square. It is a fine grained, clean, reddish coloured timber resembling close-grained cedar. It weighs dry about 35 lbs. per cubic foot, has a modulus of rupture of about 8000 lbs. per square inch and resistance to compression of 6000 lbs. per square inch.

This timber unsheathed resists teredo very well indeed ; it is a rare thing to see heart of totara which has been attacked by the teredo—I have never seen it myself. It is, however, attacked by limnoria, particularly about water level, and it is generally eaten away from the outside.

It is now practically impossible to obtain this timber in lengths suitable for piles, but a fair quantity is obtainable for walings and bracings, in lengths up to about 30 feet by 12 inches by 6 inches. The cost is now about 32*s*. per hundred superficial feet delivered at Wellington, which includes railage for some 250 miles from where it is grown, near the centre of the North Island of New Zealand. The first piles for the Queen's Wharf, which were of totara sheathed with Muntz metal, were driven in 1862–63. A number of these piles are still in the wharf, having been in place for about 55 years.

For many years past practically all of the piles used for wharf work at Wellington have been of ironbark, a hard wood imported from New South Wales. Three different varieties of this timber are used, viz., grey ironbark, *Eucalyptus paniculata*, narrow leaved ironbark, *Eucalyptus crebra*,

and broad leaved ironbark, *Eucalyptus siderophloia.* All of these timbers are susceptible to attack by the teredo, and if unsheathed are soon perforated.

Until recently ironbark piles could be obtained without difficulty up to 60 feet long, with a circumference of over 60 inches at the head, tapering to 40 inches at the point, for from 3*s.* 6*d.* to 4*s.* 3*d.* per lineal foot, c.i.f. Wellington. Owing to the strength of ironbark in compression and in tension it is a very suitable timber both for piles and beams. It has a modulus of rupture of about 18,000 and an ultimate resistance in compression, on the grain, of 10,000 lbs. per square inch; its weight is about 70 lbs. per cubic foot. A number of ironbark piles in our wharves have been spliced. This was occasioned by decay starting from pipes which existed at the heads of the piles, and, in several instances, this was due to damage caused by the teredo which obtained access to the timber under the sheathing at bolt holes.

Jarrah Piles.—A number of jarrah piles (*Eucalyptus marginata*) have been used in the construction of the Railway Wharf; in all cases these piles were sheathed with Muntz metal and are in good condition after 30 years of use.

Cast Iron Screw Piles.—A portion of the Queen's Wharf was built in 1865 with cast-iron screw piles supporting wrought iron rivetted girders, the bracings and walings were also of wrought iron. After 22 years of use the girders became badly corroded and were replaced with timber, and in 1915 the cast-iron piles were removed and timber piles carrying heavy beams substituted. It was found that the cast-iron piles after 50 years' use were in comparatively good order, although the outer skin had become softened and could be cut with a knife.

Braces and Walings.—Walings are usually 12 inches by 6 inches, fixed with the bottom edge 6 inches above L.W.O.S.T. Originally all walings were unprotected at the ends and joints, and were secured to the piles by metal bolts. The timber principally used for this work was totara, but a fair quantity of jarrah has also been used. It was found that the timber was quickly attacked by limnoria, particularly at the ends of the beams and at all joints. The life of the stick was prolonged if mussels, etc., were cleaned off regularly, but in many cases the walings were badly eaten after being down 7 or 8 years. The timber was well tarred and coated with hot pitch before being used.

Since 1906 it has been the practice in all new works, and in renewals, to cover the ends, as also the joints and intersections at piles, with Muntz metal, securely attached to the timber with Muntz metal nails. This has been found to increase the life of walings very considerably, and it may now be assumed that walings of totara, well tarred and pitched, with Muntz metal protected ends, joints, and intersections, if kept comparatively clean from mussels and marine growth will stand on the average for 15 to 18 years.

Braces are now, and have been for the last 10 years, all protected at their lower ends with metal where they are attached to the piles. Formerly the ends of braces were not so sheathed and they were quickly attacked by limnoria, so that after from about 8 to 10 years they had to be

renewed. Since protecting the ends with Muntz metal their life has been increased, and it is found that they will stand for about 15 to 18 years.

Sheathing and Metal Bolts.—The practice at Wellington has always been to use metal sheathing for the protection of all piles, from at least 12 inches below ground level to 6 inches above H.W.O.S.T. All walings, the lower end of braces, and the lower ends of fenders and bollards were bolted with metal bolts furnished with metal nuts and washers. Some of the metal which is said to have been used in 1862 is still on the piles and is in comparatively good order, as will be seen from specimen (marked S 9). A number of the bolts have been renewed from time to time as it has been found that the metal had become deteriorated by the partial solution of the zinc content so as to have very little strength, but all of the metal sheathing and bolts which were used 30 or 40 years ago may be considered to have been good and well suited for the required purpose.

Some of the bolts which have been removed from the Queen's Wharf, after being in use 39 years, are perfectly sound and good; two samples of brass bolts marked (M 3, A, and B) have apparently been cast, but whether imported from England or cast locally I am unable to say. Another sample (marked M 1) is of copper, and is believed to have been in the Queen's Wharf since it was built in the sixties of the last century; it is apparently in as good order as when it was originally put in. A Muntz metal bolt taken from a dolphin in the harbour (marked M 2), after being in position for 30 years, is still in comparatively good order.

Specimens of Muntz metal taken from Jervois Quay, after being in use for about 25 years (marked M 5, A and B, M 6, M 7), show deterioration very distinctly. It has been found that metal bolts used since 1890–95 have not been at all satisfactory, and have lost their strength after a comparatively short time. A specimen (marked M 9) taken from Glasgow Wharf in 1910, after only some 9 years' use, showed marked deterioration, as do also specimens (marked M 10, M 11, M 12) taken from the Glasgow Wharf. The worst metal of which I have had experience is that in the bolts which were used in the King's Wharf; these are of yellow metal (specimens marked M 13, A and B, M 14, M 15, M 16). These bolts in many instances were found to have become seriously deteriorated, after having only been some 4 years in position.

I may say that previous to 1912 the practice was to include all sheathing and metal bolts required for new wharves in the contracts under which the wharves were erected. The metal was obtained by the various contractors from different manufacturers. Since 1912 the practice has been for the Board to provide all metal bolts, sheathing, and nails for any work; these they procured from a reputable British manufacturer.

Owing to the deterioration which has occurred in the metal bolts and sheathing more recently used, it was determined to make a change, and for the past 4 years the greater part of the metal used has been a hardened copper, composed of 99 per cent. copper and 1 per cent. of tin. So far as can be judged up to the present time, this metal appears to be satisfactory. A specimen of sheathing (marked S 8) was removed after having been in service 4 years, and a bolt (marked M 17) is of about the same age.

Judging, however, from the experience obtained from a beacon which was erected some 2½ years ago near the entrance to the harbour, this metal is not likely to give good results where it is exposed to continual wave-action. A specimen (marked S 8A) was removed from a raker pile about 1 foot above low-water level. It has become very thin and is perforated, having been worn by the continual action of the waves. From low-water level to about 1 foot below high-water mark the copper is quite bright, although it has not deteriorated; the action ends a little below low-water level.

Since the outbreak of war it has been found impossible to obtain hardened copper sheets and rods, and a quantity of genuine Muntz metal, which was obtained from England, has been used in repair work.

Special attention is drawn to samples of metal taken from the King's Wharf, a contract for the construction of which was entered into in September, 1906. The sheathing is marked S 5, S 6, S 7, and the rods M 8, M 13 (A and B), M 14, M 15, and M 16.

Both the sheathing and the rods, which were used for making bolts, were supplied to the contractor for the wharf by a local firm, the sheathing having been manufactured by a German company (The Crausauer Copper and Brass Manufacturing Company) and the rods by an English firm. Some 2 years after the completion of the wharf, in 1910, it was found that both the sheathing and bolts showed very marked indications of deterioration, and it was deemed necessary to renew a large number of the bolts and also to protect many of the piles.

An analysis of the sheathing by Professor T. H. Easterfield, Professor of Chemistry, Victoria College, New Zealand University, gave the following results:

Copper	58·9
Zinc	38·1
Tin	0·8
Lead	1·2
Iron	1·0

While an analysis of P. H. Muntz & Co.'s Three Crown sheathing gave:—

Copper	60·8
Zinc	38·7
Tin	Trace
Lead	0·5
Iron	Trace

Further, an analysis of borings taken from the centre of a bolt from the King's Wharf gave the following results:—

Copper	54·4
Zinc	41·7
Iron	1·6
Lead	1·3
Tin	0·5
Difference	0·5

These analyses show that the metal used on this wharf was not of the same composition as genuine Muntz metal, being rather of the nature of stereo metal, and unsuitable for the purpose for which it was used.

Concrete Sheathing.—A large number of piles in the King's Wharf have now been protected with concrete; altogether, some 574 piles have been sheathed in the following manner:—

A number of light steel casings were constructed; they were made in two pieces with vertical joints and with flanged ends, to enable them to be readily placed in position around a pile by a diver, from about 12 inches below ground level to an average of O.L.W.L. The casings were slightly oval in section, to leave room for the connecting pipe and to provide for from 4 inches to 6 inches of concrete around the piles.

After the bottom had been cleaned and the casings placed in position, the concreting pipe, which was an ordinary 4-inch wrought-iron water pipe, made in various lengths and furnished with a joint which leaves no obstruction in the pipe, was passed down the inside of the casing from the deck of the wharf to ground level. The top of the pipe was fitted with a hopper.

The whole quantity of concrete required to protect the pile was mixed fairly wet at one operation. The concrete was composed of 1 part of cement to 3 parts of aggregate, which latter was a river gravel containing a surplus of clean sand of varying sizes, screened to remove all stones larger than 1 inch. The concreting pipe is lifted a few inches from the bottom, and the concrete is then rapidly filled into the hopper, from which it passes down the pipe till it is full and concrete shows in the hopper. The hopper is kept full as the concrete passes down, and the pipe is raised slightly when the concrete ceases to flow.

Great care must be exercised to see that the bottom of the concreting pipe is always embedded in the deposited concrete, so that water does not come in contact with the concrete which passes through the pipe. Usually the concrete is brought up to the required height, with the foot of the concreting pipe embedded several feet into the soft deposited concrete inside the casing. The concrete is not carried higher than a little above low-water level, the remainder of the pile being, of course, easily re-metalled.

This method of protecting the piles of the King's Wharf was put in hand 5 years ago, and up to the present time it has proved quite satisfactory. The cost of protection with concrete worked out at 6*s.* 8*d.* per lineal foot, where a number of piles were done at a time, but for a small amount of work the cost would be considerably greater.

Reinforced Concrete Wharves.—The Clyde Quay Wharf, which is a reinforced concrete structure, was built by contract and completed in 1909. The piles are 18 inches square, spaced 20 feet longitudinally and 9 feet transversely. The main beams run longitudinally from pile to pile. They are $13\frac{1}{2}$ inches wide and 18 inches deep over all and are strengthened by means of 12-inch by 12-inch struts from the under side of the beams to the piles. Transverse beams 3 feet 4 inches apart and 9 inches wide by 15 inches deep divide the deck into panels 9 feet by 3 feet 4 inches.

The deck of the wharf, which is 12 feet above the level of O.L.W.S.T., is $7\frac{1}{2}$ inches thick. Vertical double transverse bracing 12 inches by 12 inches and longitudinal and transverse walings 12 inches by 12 inches and 10 inches by 12 inches respectively connect the piles together. The bottom edge of the walings is placed 2 feet above O.L.W.S.T.

The concrete was composed of a 1–2–3 mixture, the aggregate being screened river shingle from which all sand and gravel larger than $\frac{3}{4}$ inch had been removed. The sand was river-bed sand retained in a 76 by 76 sieve and passing a 10 by 10 sieve. The cement used was locally made and conformed to the British Standard Specification of 1904. 196 piles were driven to 4 feet above level of O.L.W.S.T., and after being duly secured in their proper places by needling timbers, were stripped down to the level of the walings to expose the reinforcing rods. Extension rods, which were secured to the main rods by 18-gauge soft iron wire, were carried up to the heights needed and the pile extensions, wales and braces were afterwards boxed and concreted; the walings and lower portions of the pile extensions being first completed.

Difficulty was experienced in filling the concrete solidly around the reinforcing rods at the intersections of the wales and braces with the pile extensions, and at the intersections of the main and secondary beams with the pile extensions, and more clearance between the rods than was given is necessary.

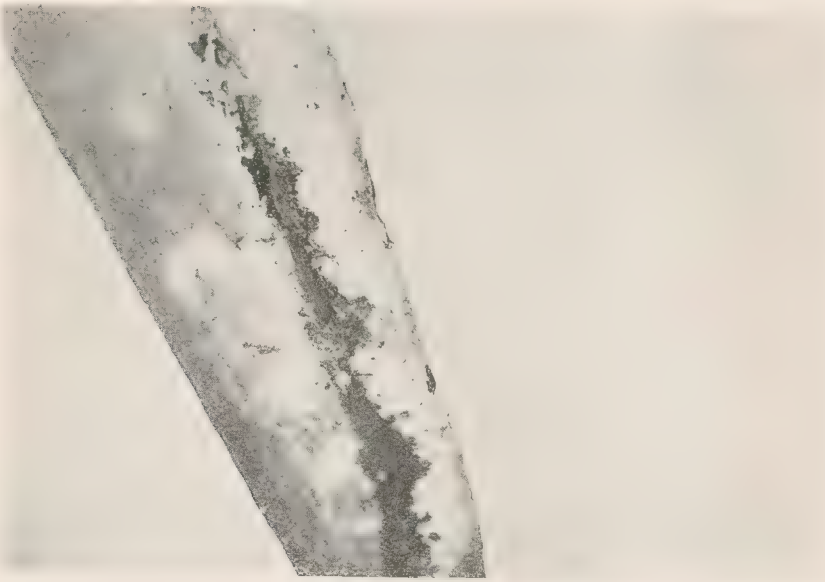
Some difficulty was also encountered in getting solid concrete in the inclined braces and pile extensions, as there was a tendency for the fine particles to separate from the coarse portion of the aggregate when the concrete was placed in position.

With regard to the condition of the wharf, for some 12 to 18 months after it was completed there were no signs of rusting or deterioration. Afterwards some patches of rust were apparent on the under side of the beams, but more particularly in the transverse bracing, and here and there on pile extensions. These defects were cut out and patched. During the past 4 years a moderate amount of cutting out and patching has been done, the cost of which has not been large. In the transverse bracing, well above high-water mark, it was noticed that in a number of cases a rusty mark first showed, and that later on a crack developed along the line of the reinforcing bar. On cutting away the concrete down to the reinforcement it was found that corrosion had been going on and spreading up and down the bar into what was apparently solid and sound concrete. In most cases the concrete and reinforcement when opened out were dry. The concrete appeared to be sound and solid, but apparently either there was not enough cover over the reinforcement or the concrete was sufficiently porous to permit of the passage of moisture through it. No waterproofing material was used, Plate XXVII.

In a few cases cracks appeared in the pile extensions, i.e., the prolongation of the pile above low-water level, which was built with the wales and braces after the pile had been driven. On opening out the concrete, down to the steel reinforcing bars, these latter were found to be corroding although both the concrete and steel were dry.

The deck, which is $7\frac{1}{2}$ inches thick, reinforced with $\frac{3}{4}$-inch bars at

WELLINGTON, NEW ZEALAND.



Clyde Quay Wharf, Wellington, New Zealand.

Longitudinal strut under outside beam in 3rd bay from outer end of wharf on east side. In position 8 years. Centre of damage to concrete about 1 foot 6 inches above H.W.O.S.T.

Clyde Quay Wharf, Wellington, New Zealand.

Transverse brace on outer tier of Piles. In position 8 years. Damage to concrete about 5 feet above H.W.O.S.T.

$3\frac{1}{2}$-inch centres, is covered with $4\frac{1}{2}$-inch wood blocking. Cracks appeared in the deck before the blocking was placed in position, but so far as can be judged by examination of the under side of the wharf these have not developed further.

Rusting has appeared to a slight extent on the under side of the deck, and patches of concrete here and there have been cut out and made good. This damage has, I think, been caused by the displacement of the reinforcements during construction, and also by insufficient cover having been provided.

Waterloo Quay Breastwork, which is 1,192 feet long, has been built somewhat differently in reinforced concrete. It should be noted that there are no horizontal walings or vertical bracing, but one of the piles has been battered and moulded with the outside pile to form a support for the vertical and horizontal timber fendering. A triangular diaphragm and a heavy and deep cap tie the heads of the pile and the face wall together. The beams run longitudinally dividing the deck into panels 15 feet by 9 feet 11 inches. The deck varies in thickness from 10 inches to 12 inches and is covered with $1\frac{3}{4}$ inch of Neuchatel asphalte.

After construction was started it was found that the cover provided over the reinforcement in the triangular diaphragms between the under side of the caps and the outermost pile extensions was insufficient, and this cover was increased by 1 inch, making it 9 inches altogether.

There is up to the present time no sign of rusting, or deterioration of the concrete, but cracks across the deck, at approximately the quarter span, have developed and are shown through the asphalte covering.

All bending of the steel was done cold by means of hydraulic gear improvised for the purpose. The concrete for the piles was composed of one part of cement, two parts of river sand and three parts of washed river gravel, graded from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch. The concrete for the deck and beams was originally in the proportion of 1–2–4, but after a portion of the work had been executed, this was altered to 1–2–3. The cement was all of New Zealand manufacture. Each consignment of from 30 to 50 tons was tested to see that it conformed to the British Standard Specification (revised March 1915).

Rough compression tests of the concrete were made from time to time, the practice being to fill circular moulds 5·05 inches diameter by 5 inches high with the mix that was used in the work. The results obtained were irregular, due probably to separation of the aggregate in the small amount of concrete which was used when placed in the mould. The compressive strength of blocks made from the 1–2–4 mixture, six months old, varied from 900 lb. per square inch to 2,900 lb. per square inch, while that of the 1–2-3 mixture varied from 2,100 lb. per square inch to 4,100 lb. per square inch.

Pipitea Wharf.—The construction of this wharf in reinforced concrete was only begun shortly after the war broke out.

Mass Concrete.—A considerable quantity of concrete has been used in Wellington Harbour for the construction of face walls. Cross bulkheads were placed at such intervals as would permit a length of wall up

P 2

to the height of a lift to be filled with concrete at one operation, i.e. without stopping after concreting was begun.

The depositing was done with wooden depositing skips (from ½ cubic yard to 1 cubic yard capacity) made with bottom doors which were tripped after the skip had been lowered to the bottom.

It was found that the best results were obtained by making the sections of moderate length, and depositing at one end until the concrete was up to the top of the boxing, before moving along the section.

The skip lodged in the soft concrete before the concrete in it was discharged, and there was less action by the sea-water on the unset concrete than when deposition was made all over a section. When a section was filled it was allowed to set, after which the laitance which had formed and settled on the surface was removed by divers, using jet pumps operated from a punt, before another lift was deposited.

In depositing concrete in this manner there is always a considerable amount of laitance formed, a portion of which becomes mixed with the concrete and weakens it. There has not, however, up to the present time, been a failure of any of the walls in Wellington Harbour due to this cause, although at several places local defects have occurred.

Analyses of the water of the harbour were obtained in 1910, and were found generally to correspond with that in the Atlantic and Pacific oceans.

The results showed :—

Total solids	3·7 per cent.
Chlorine	2·0 ,,
Lime	·06 ,,
Magnesia	·21 ,,
Sulphuric anhydride . . .	·26 ,,

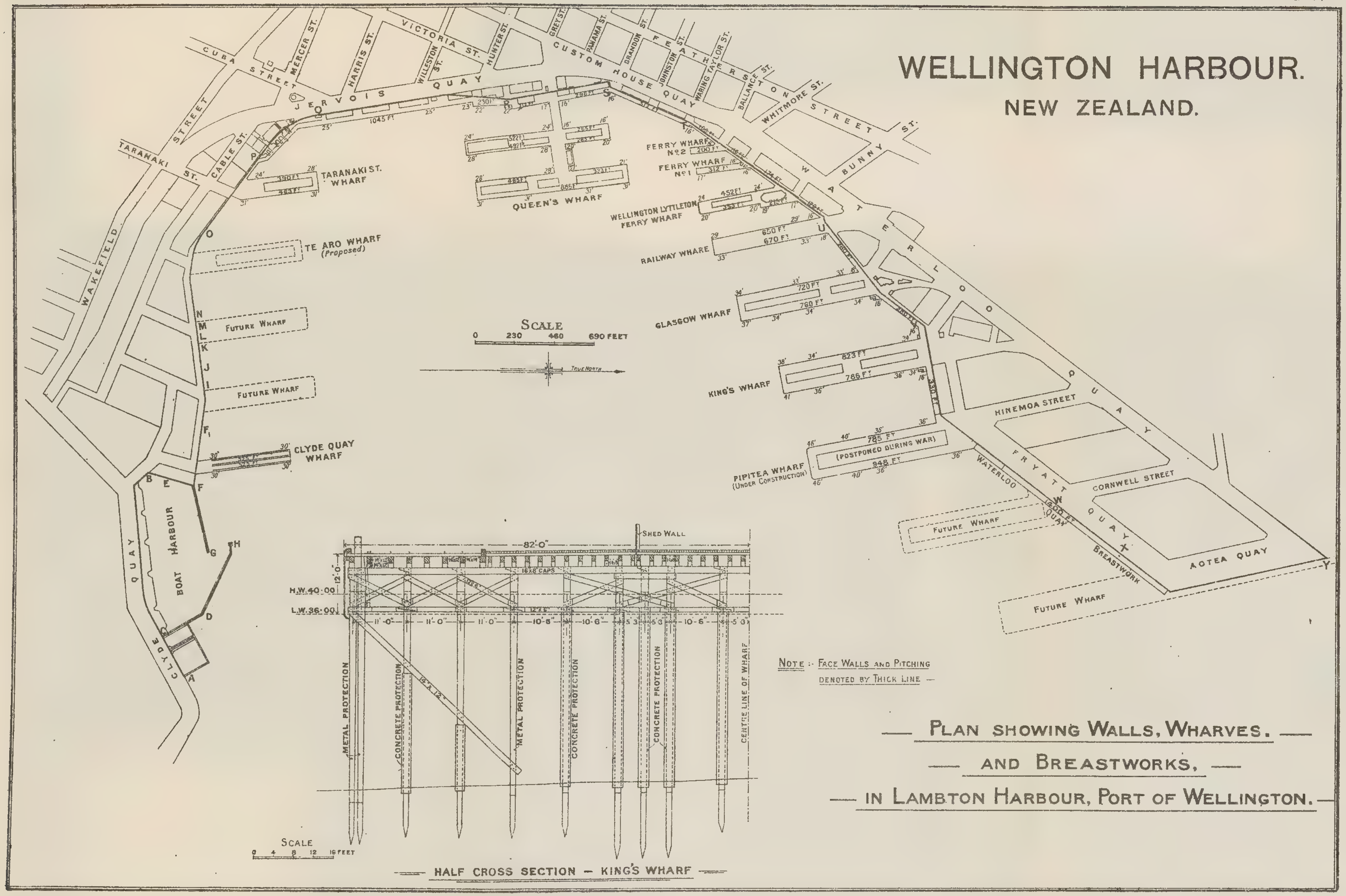
The only fairly large stream discharging into the harbour is the Hutt river, the outlet of which is some six miles distant from where the wharves are situated. Storm-water culverts discharge into the harbour, but the sewage is carried by a separate system, with an outlet to the open sea in Cook Straits.

The concrete walls generally were in good condition, but small pockets have been formed irregularly here and there. The concrete is composed of 1 of cement to 7 of river shingle.

The upper portion of some of the wall having proved defective it was rebuilt in 1912. The cause of the failure could not be determined, but it was thought to be due, perhaps, to vibration caused by seas acting on the boxing, before the concrete within had properly set.

Generally speaking the concrete is in good order, and practically no repair work has been found necessary. A few pockets up to about 8 inches deep exist from low-water mark downward; these are in most cases due to the green concrete having broken away when the profiling was removed. Samples of concrete from these walls may be of interest, and are sent herewith, together with detail drawings of the work.

FIG. 31


WELLINGTON HARBOUR.
NEW ZEALAND.
CUBA STREET
MERCER ST.
HARRIS ST.
VICTORIA ST.
WILLESTON ST.
HUNTER ST.
GREY ST.
PANAMA ST.
BRANDON ST.
JOHNSTON ST.
WARING TAYLOR ST.
BALLANCE ST.
FEATHERSTON STREET
WHITMORE ST.
BUNNY ST.
JERVOIS QUAY
CUSTOM HOUSE QUAY
TARANAKI ST.
CABLE ST.
WAKEFIELD STREET
TARANAKI ST. WHARF
QUEEN'S WHARF
FERRY WHARF No 2
FERRY WHARF No 1
WELLINGTON LYTTLETON FERRY WHARF
TE ARO WHARF (Proposed)
RAILWAY WHARF
GLASGOW WHARF
KING'S WHARF
PIPITEA WHARF (UNDER CONSTRUCTION)
(POSTPONED DURING WAR)
FUTURE WHARF
CLYDE QUAY WHARF
BOAT HARBOUR
CLYDE QUAY
WATERLOO QUAY
HINEMOA STREET
FRYATT QUAY
CORNWELL STREET
AOTEA QUAY
BREASTWORK
SCALE
0 230 460 690 FEET
TRUE NORTH
NOTE :- FACE WALLS AND PITCHING DENOTED BY THICK LINE —
— PLAN SHOWING WALLS, WHARVES. —
— AND BREASTWORKS, —
— IN LAMBTON HARBOUR, PORT OF WELLINGTON. —
SHED WALL
82'-0"
H.W. 40·00
L.W. 36·00
METAL PROTECTION
CONCRETE PROTECTION
CENTRE LINE OF WHARF
SCALE
0 4 8 12 16 FEET
— HALF CROSS SECTION – KING'S WHARF —

BELAWAN, SUMATRA.

By SOMERS H. ELLIS, M.Inst.C.E.

Deterioration of Hardwood Members of Wharves at Belawan, Sumatra.

The port of Belawan, important as being the outlet for rubber and tobacco from the fertile districts of Langkat, Deli and Serdang on the east coast of Sumatra, is situated on the tidal estuary of the Deli river, about 3 miles from the sea. The river itself is a small one, and the estuary at this point is $\frac{1}{4}$ mile wide, so that the water is salt at high tide and brackish on the low ebb. The surrounding district is low and swampy for 3 miles inland; the water of the estuary is muddy, and the banks consist of river-deposited silt to a depth of 120 feet or more.

A tracing is appended showing the cross-sections of two wharves distinguished as A and B, see Fig. 32.

Wharf A, which was intended only as a temporary structure to serve a pontoon with gangways for 5 or 6 years, was completed in the spring of 1914. It is constructed entirely of hardwood, the piles being hewn logs, 14 inches by 14 inches and from 35 to 40 feet in length, and the bracing and deck beams were of 12 inches by 6 inches sawn half-timbers. The front piles, before being driven, were encased with $1\frac{1}{2}$ inch thickness of 1 to 2 Portland cement plaster on expanded metal for the portion from 1 foot 6 inches below mud level to the bottom of the bracing—a few inches above low-water level of ordinary spring tides.

The timber used is known in the Straits as ballow, and comprises two or more slightly differing species of the genus *shorea*. A corresponding timber of almost identical characteristics is called "yacal" in the Philippine Islands, and "selangan batu" in Borneo. The weight, when dry, varies from 50 to 60 lb. per cubic foot. The wood is hard, tough and durable in any ordinary situation, and is looked upon as the standard first-quality timber for outdoor constructions of a heavy nature.

On examination of the wharf in November, 1916, six piles, out of about thirty which were always partially immersed in water, were found to be so honeycombed by the *Teredo navalis* as to be seriously weakened. One was entirely bored through, as were some of the lower bracing pieces. All the piles in the wharf were bored by the teredo to a depth of 1 inch or more from the surface of the wood, over the zone extending either from mud level, in the case of the interior piles, or from the top of the cement coating in those of the front row, to a height of about 5 feet above low water level (i.e., 2 feet 6 inches below high water). The bracing in the same zone was similarly attacked.

On re-examination in July, 1917, the process was found to have proceeded farther on the same lines, the boring having reached a depth of 2 inches from the surface on many of the piles. Within the cement casing, or below mud-level, the evidence of attack by the teredo ceased an inch or two below the edge of cover to the pile.

As a remedial measure, the piles are now being cut down to solid wood on the portion attacked, and encased in reinforced concrete, 4 inches thick, laid within a wooden mould at low tide. The lower longitudinal waling is being removed entirely, and the cross-bracing is being renewed with local timber where necessary. It is intended to replace the wharf with a more permanent structure in the course of a few years.

Wharf B.—The second wharf, B, was constructed during 1915 of steel joist-section piles, with a superstructure of steel channels and a timber deck. The steel is maintained generally in good condition by being annually painted above low-water level, and shows no sign of pitting or other deterioration where constantly immersed.

Vertical fender posts of 12 inches by 12 inches sawn ballow timbers are bolted to the front of the wharf. These have been attacked by the teredo from their lower ends, and the inside of the wood has been honeycombed as high as high-water mark, leaving the surface intact and outwardly sound. The wood received two coats of tar before being put in place. Nearly all the fender posts have now to be renewed or scarfed with fresh wood at their lower ends, which are being protected by a covering of galvanised sheet iron, nailed over the wood.

BOMBAY.

By P. GLYNN MESSENT, C.I.E., M.Inst.C.E., Chief Engineer Bombay Port Trust.

Timber has never been used here for permanent works in the sea owing to the rapid destruction caused by the pholas and teredo.

There are no structures of re-inforced concrete in the sea at this port, but several quay walls of concrete blocks up to 2 feet above low water, with rubble masonry faced with ashlar above. Some of these walls, which have been built more than 40 years, show no signs of deterioration. I have had no experience of concrete coated with tar.

I have had my office records carefully gone through, and have found the following reports on the ravages of teredo and pholas in timber, of which I enclose copies.

(1) Report dated 7th February, 1889, on the repairs done to the greenheart gates of the 55 feet entrance by the late Mr. W. W. Squire, M. Inst.C.E., Chief Engineer, Bombay Port Trust 1892–98.

(2) Report dated 8th April, 1908, on the piles of jarrah, karri and turpentine which were kept in the sea for 2½ years as an experiment by Mr. L. Savile, M.Inst.C.E., Deputy Engineer, New Dock Works, Bombay Port Trust.

I may say karri was tried for ladders and fenders in the sea, but was completely eaten away below H.W.O.N.T. in 3 or 4 years. Burmah teak has been used for temporary jetties, but it did not last more than 6 years between high and low water.

APPENDIX I.

REPORT BY THE LATE W. W. SQUIRE, M.INST.C.E., CHIEF ENGINEER.

I have the honour to report that the gates of the South or 55 feet entrance to Prince's Dock have been lifted out of the water, cleaned, examined, repaired, and replaced in position. The Prince's Dock gates are built of greenheart from Demerara, a timber which has in English waters proved impregnable to the attacks of sea-worms, and which, though the teredo is said to have been found in it many years ago, is known to resist attack longer than other timbers even in tropical waters.

North Leaf.—When the gate rose out of the water daylight could be seen through a hole in the fourth row of planking near the heel post, but in no other place. The whole surface of the gate, which was covered with barnacles, oysters, anemones and sea-weeds was first thoroughly scraped clean and washed down.

The meeting face of the sill piece was found to be eaten and chafed away throughout its whole length from 1 inch to 1½ inch in depth, except in one or two places where it had been tight against the stone sill, and there it was quite smooth and clean. The face of the timber was perforated by pholas, and fretted as if by the limnoria, though none of these creatures were actually seen. The under side of the bottom rib was also freely perforated by pholas.

The upper surface of the timber, however, on being washed and scraped clean was found with the original black varnish on it quite untouched, and not a single hole could be detected in it. The dock side of the ribs and planks was not attacked to the same extent as the harbour side, the difference being very marked. The same was observed on all the ribs. In only a very few places were there any holes at all on the upper sides. The under sides and faces were all perforated, while the upper sides were untouched, and the inner or dock side was much freer from holes than the outer or harbour side. All the ribs appeared to be attacked to the same extent except the bottom rib, the under side of which was less eaten than the under sides of other ribs. The heel post was perforated and attacked freely up and down the whole height of the gate on both sides, leaving a narrow strip between the water lines smooth and clean with very few pholas holes in it. At the bottom of the heel post there was a portion about 2 feet in height eaten away right round, about ½ an inch in depth, probably from the fact that the gate was not tight against the hollow quoin. This is where a very good deal of leakage occurs. Most of the plugs over the heads of building bolts were eaten so much as to require renewal. At the junction of the bottom rib and heel posts some damage had been done, breaking away part of the timber of both. This had been most probably caused by something being jammed between the gate and the sill. The tenon on the rib did not appear to be injured, nor were the bolts started.

The mitre post was freely attacked by pholas, especially between the second and third row of planks, and most of all below the bottom row of planks. The meeting place of the lower portion was much fretted, and

did not appear to have been touching the other gate for some time. This is probably due to the falling of the gate as the wear on the rollers increased, which prevented the bottom of the mitre posts from coming close up. The jungle wood fenders below L.W.O.S.T. were almost entirely destroyed, having been eaten away to more than half the original thickness. They were destroyed mostly on the lower side. Those above low water, which had been renewed previously, were in fairly good order, though freely attacked.

The planking in every row except the top one was much injured by pholas and teredo, especially on the harbour side, the inner or docks side being much less freely attacked, but none of the holes went through. Between levels 73·00 and 76·00 on T. H. D. the pholas was abundant, especially on the harbour side, but none of the holes probed were more than 1 inch deep. The keys in the middle head chocks and ribs were found mostly eaten at the outer ends, and were renewed where necessary.

The whole of the galvanized wrought iron work was found to be in good condition, the zinc being quite sound. The cast-iron roller carriage was quite good and had not become converted into plumbago. A few bolts were taken out for examination, and were found uninjured.

South Leaf.—When this leaf came out of the water, daylight could be seen through numbers of places in the planking in every row except the two top ones, and the gate appeared to be in a much worse condition than the North one was. The sill piece was found to be eaten and fretted and in much the same condition as that of the North Leaf. The bearing on the stone sill, however, was better, and though not damaged in such long lengths, the places where worn and eaten were quite as deep.

The under surface and sides of the bottom and other ribs were attacked by pholas to the same degree as in the North Leaf, the same difference between inner and outer faces being noticed, as well as the almost entire immunity from attack of the upper surfaces. The bearing surface of the heel post of this gate generally was in much better condition than that of the North Leaf. It showed evidences of having borne better against the hollow quoin. The worst places in the timber were from the bottom upwards for about 3 feet on the outer side, and just below the second rib from the top.

The mitre post was in the same condition as that of the North Leaf. The lower portion was a good deal eaten by pholas, and fretted as if by limnoria. It presented the same appearance of not having been tight against the other gate.

The worst part of this gate was the planking. Almost the whole of the bottom row of planks was loose and could be shaken by hand, and many of the fourth row of planks also. The fastenings (spike nails galvanized) were in nearly all cases good and holding firmly into the rib, but the planks had been eaten on the upper edges and corners and had become loose, causing them probably to work backwards and forwards on the nails till the holes were enlarged. In consequence of this working the caulking had come away in both vertical and horizontal joints. Where the planks had worked loose, the pholas was found in the rebates in the solid timber of the ribs, but in no case were any found behind the

firmly fixed planks, some of which were removed for examination. The whole of the iron work was in good condition, the zinc coating being quite perfect; only two bolts required to be removed.

In all previous examinations above low water it has been noted that the pholas only bores about $1\frac{1}{2}$ inch deep. I only find one note of a hole $1\frac{3}{4}$ inch deep, and I have since only found them of this depth in the jungle wood fenders. Fortunately neither the teredo nor the pholas appear to have penetrated to any depth into the main timber of the gates for, when dressing off the sill pieces, the solid heart wood was found without a trace of either, and in all the ribs, from which pieces were cut off, the solid uninjured wood was found in no case more than $1\frac{1}{2}$ inch from the outer surface.

Extracts from Appendix No. 1, which accompanied the Chief Engineer's Report to the Secretary of the Bombay Port Trust:—

Notes on 66 *feet Gates* (*Northern Entrance*).—Highest trace of pholas on greenheart at level of 19 feet 0 inch on sill (77·00 on T.H.D.) sapwood slightly affected, heartwood showed very slight traces. Several oak keys observed to be destroyed by teredo. These were cut out and replaced one by one with Malabar teak keys boiled or soaked in corrosive sublimate.

Haider wood fenders at 71 feet 6 inches on T.H.D. were very much affected and almost destroyed by pholas. Haider wood fenders at 77 feet 6 inches were slightly affected by pholas. I detected no trace of teredo in either greenheart or haider.

55 *feet Gates* (*Southern Entrance*).—These gates are five or six times more affected by pholas than the Northern Gates. Fenders attached at same level as above. Sapwood on top of rib (at 73 feet 6 inches) and next heel post South side were full of pholadidae.

The sapwood of heel post at the same level was also freely attacked. Height of tide at this point, 71 feet 6 inches.

On the removal of the damaged fenders, 26th October, 1882, the pholas was found all along the ribs where the fenders had been.

Observations on the Difference of the Injuries Inside and Outside the Gates.—It has been mentioned above that there was a marked difference in the inner and outer sides of the gates, the side next the dock being much less attacked than that next the harbour. This has also been observed in the Liverpool Docks, and is I believe partly due to the fact that the teredo and pholas are produced from eggs which, before attaching themselves to the timber in which they spend their lives, are in a free state, and the eggs would be naturally more numerous and vigorous in the everchanging water of the open harbour than in the confined water of the dock, which is only open to the sea a few hours each day. It was observed at Liverpool many years ago that these creatures are less destructive in docks into which sewage flows. The quantity of impurities that could be classed as sewage in the Prince's Dock is very small, but it is possible that it may be enough to account for some of the difference noted. Probably both causes contribute to save the inner side of the gates.

The teredos found were, I believe, the ordinary *Teredo vivalis.* Only one specimen of the shell armament of the head was secured in a perfect

condition, and in all cases the shell had been separated from the rest of the body from the drying up of the latter. The hole bored by this creature is very tortuous, and as no more of the timber of the gates than was necessary for repairs could be cut away it was impossible to secure a complete specimen. The fragments of the wormlike body which were found were of a dull flesh-coloured red, and were fringed along both sides with small legs rather like a centipede in appearance. The longest piece found was 15 inches. The holes bored by the teredo were found of all sizes from $\frac{1}{16}$ inch in diameter up to $\frac{1}{2}$ inch diameter. The pholadidae all appear to be of one species, *Pholas striatus*, the markings and general formation of the shell being the same. They were of all sizes from $\frac{3}{8}$ inch long by $\frac{1}{8}$ inch and less in diameter to large shells nearly $1\frac{1}{4}$ inch in length and $\frac{3}{4}$ inch diameter. Some of the shells are much more pear-shaped than others, the growth probably being in the direction of the length at first and afterwards widening at the inner end. Both teredo and pholas were found at the bottom of the gate, and extending up to about 15 inches above mean sea-level and about 6 inches above lowest high-water mark. When the paddles in the sluices were drawn in 1882 the pholas was found in the greenheart spear rods at 81·00; and in the teak piles removed from the Elephanta Piers the highest level was about mean sea-level. The teredo was noticed in the sapwood of the Prince's Dock gates at 81·75 or 18 inches above mean sea-level in 1883, while at that time there were no perceptible traces of pholas at 77·00 which is about L.W.O.N.T.

From other observations it would appear probable that neither of these creatures can exist if left exposed out of water more than the time between two tides. The highest levels at which they have been observed correspond very nearly with the level of lowest high water, which is usually taken at 81·00 T.H.D. The lowest recorded high water was on the 29th September, 1888, when the level was 80·66, and the predicted height of tide on the 18th October, 1889, is lower still, 80·50. Such extreme tides, however, occur only twice or thrice in the year.

APPENDIX II.

EXTRACT FROM REPORT BY L. H. SAVILE, DEPUTY ENGINEER, NEW DOCK WORKS.

With reference to the letter dated 31st March, 1908, from Messrs. Millars Karri & Jarrah Co., I have the honour to report that the two jarrah piles received from them were fixed at the end of the new temporary oil jetty in December, 1905, and have therefore been in position $2\frac{1}{4}$ years. I cut pieces off these piles at about level of 76·00, or 4 feet above lowest L.W.O.S.T., at the beginning of this month, and from these it would appear that the sapwood is readily attacked by both teredo and pholas, and in the case of one pile the teredo has got into the heart of the wood. I am of opinion that in a few more years this pile would be destroyed. The other pile, which appeared to be a particularly hard piece of karri, showed no signs of being destroyed by the teredo, but had

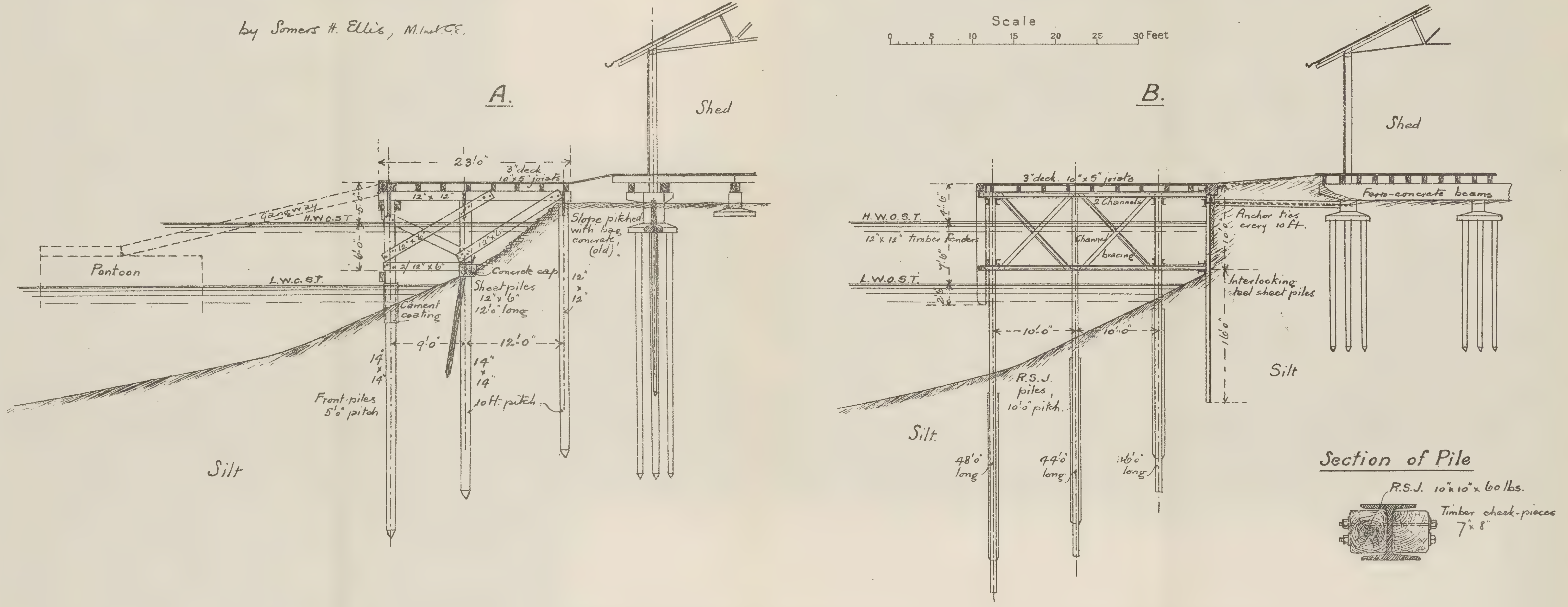
FIG. 32.

Drawing to accompany Note dated 3rd Aug. 1917, addressed to the Secretary, Committee of the Inst. C.E. on the Deterioration of Structures Exposed to Sea Action.

by Somers H. Ellis, M.Inst.C.E.

BELAWAN, SUMATRA

Cross-Sections of Wharves belonging to Ocean S.S. Co.



been attacked by the pholas in one or two places. From its appearance I should say it would remain sound for several years.

I might mention that there were two turpentine piles fixed at the same time, and these have stood so far very well, as there is no sign of attack by teredo and only a few pholas holes to a trifling depth. I should say that this timber, from the appearance of teak piles near, would last as long, if not longer, than the teak in Bombay Harbour. I notice that the pholas which has attacked the turpentine seems to be of a different kind to that which attacks teak.

COLOMBO.

By A. D. PROUSE, M.Inst.C.E., Harbour Engineer.

The sheltering works in connection with the Harbour at Colombo consist of four main Breakwaters, the total length of which, in the aggregate, amounts to 9,780 feet. These works have been arranged to enclose and protect a harbour of 643 acres in extent, having a depth varying from 40 feet to 33 feet at low water. The tides rise ordinarily about 2 feet.

The South-west, North-west, and an additional arm running from the original South-west breakwater, all consist of concrete blocks, varying in weight from 14 to 31 tons, each arranged in inclined slices with sloping bond, and founded at suitable levels dependent upon the depth of the sea-bed on which the different works are constructed. In all cases the lowermost blocks are bedded on a rubble mound, the seaward footings of which are protected either by a wave-breaker of concrete blocks laid in pell-mell form, or by heavy masses of rubble deposited *à pierre perdu.*

The width of the structures referred to varies from 36 feet at coping level to 32 feet. The formation level to which the blocks in the breakwaters are generally laid is 8 feet above low water, on which there is a concrete-in-mass capping, the outer edges of which are generally about 11 feet 6 inches above low water, the surface being cambered. The mass capping is, therefore, for the most part about 4 feet thick in the centre of each work, and 3 feet 6 inches at the sides.

The proportions adopted for the concrete used throughont the works, both in the blocks and in the capping, since 1898, were six parts of broken stone, shingle and sand to one of Portland cement; no block was laid in the work until it had been made about three months.

The South-west breakwater was commenced in 1875 and completed in 1885. The remainder of the works were commenced in 1896 and continued, practically without interruption, until 1912, when the complete harbour, with coaling jetties, reclamations, graving dock, patent slip, and other accessory and additional works, on the shore and otherwise, were finished, and the entire undertaking was formally inaugurated by His Excellency Sir Henry McCallum, the Governor of Ceylon at that date.

Before the commencement of these works, an outline plan of which is attached hereto, the entire bay, or roadstead, at Colombo, was open to the south-west monsoon, and no sheltered berthage, or protective works, were available; so that when these important structures were initiated and

designed very few data were available as to the activity of the teredo and limnoria on timber work. It was assumed that, in all probability, the effect of teredo action would be unusually acute, and inasmuch as one of the first operations in the carrying out of the new breakwaters necessitated the landing of heavy plant, appliances, cement and other materials, all in large quantities, a temporary jetty was erected at the southern end of the harbour, near the root of the South-west breakwater. This jetty was formed of creosoted Baltic fir, imported from England, the timber having been previously treated with 14 lb. of oil per cubic foot of timber. Experience, however, showed that, in consequence of the activity of the teredo, this jetty was so weakened by worm action that in less than 2 years from the time of its construction it had to be superseded by a concrete wharf, which is still in existence and is in a good state of preservation.

Inasmuch as the works referred to have extended over a period of 40 years, the record of their construction affords the results of valuable experience as to the action of sea-water on concrete of the ordinary description, when employed in sea structures in the form of blocks. In the case of these works it is satisfactory to note that the use of concrete in the form adopted has been attended with complete success; no failure or disintegration of the material, employed in such large quantities, having anywhere been observed.

Before the commencement of the works great care was taken, by experiment, to arrange the proportions of broken stone, shingle, sand and cement, required to form the concrete; so that when mixed and deposited, it should be such as to produce entirely solid work, free from vacuities into which sea-water, either falling on to the breakwater or otherwise, could enter.

The South-west and North-west breakwaters, particularly the former, are exposed to an abnormally heavy sea-stroke. Before the formation of the wave-breaker along the seaward face of the former, the waves and broken water rose to a great height above the structure, falling heavily on its surface. Nevertheless no damage was caused, after the completion of the breakwater, nor was the character of the concrete therein prejudicially affected.

The North-east breakwater consists of a rubble mound deposited from a temporary staging, the object of the latter being to so distribute the rubble that the sea-action thereon would be minimised, and the quantity of the material required reduced as far as practicable, thereby avoiding unnecessary and wasteful dispersion of stone by wave action.

In view of the extreme activity of the teredo, in these waters, on timber structures, iron was adopted as the material for the temporary staging required for the last-named breakwater, keeping in view the utilisation of the portions of the piles which were available for removal, above the surface of the rubble, after the completion of the works, and their subsequent use in the construction of certain small permanent jetties which were required along the eastern margin of the harbour.

It will be observed from the annexed plan, Fig. 33, that the North-west Breakwater is an island work, *i.e.* it is separated from the land by the

Northern and Southern entrances to the Harbour, the former being 700 feet and the latter 800 feet in width. Across the opening between the outer end of the North-east Breakwater and the northern end of the North-west Breakwater, the iron staging to which reference has been made, was carried across the entrance opening, so that the North-west Breakwater was at all times connected thereby with the shore, and was, therefore, available for the traffic of workmen, etc., over the same.

The form of this last-named staging corresponds with that required for the North-east Breakwater, viz., an iron three-pile structure, the piles being screwed into the sea bed.

On the completion of the North-west Breakwater, when this staging was no longer required, the superstructure of the stage was removed, the piles were drawn, and the waterway of the opening was left clear for use.

The viaduct piles across the opening were placed in position in the early part of 1897 and were removed at the end of 1905, so that they were exposed to sea-action for a period of nearly 9 years, during which a marine growth had formed upon the underwater surface of the iron piling. This had become of considerable thickness and had completely covered the surface of the ironwork, with the exception of certain small isolated spots of about 1 inch in diameter, where shellfish had adhered, but had become detached. With the exception of these spots the iron was perfectly preserved by the above-mentioned growth, so much so that when the piles were removed, after 9 years' service, and the adhering growth was scraped off, their surface was found to be covered with the original coating of Dr. Angus Smith's preservative composition.

The scattered spots on the piles, on the other hand, had become in time pits or depressions in the surface of the iron, each depression being completely filled with black powder. This was only revealed when the powder was scraped out. The pits so formed were of appreciable depth, and if the deterioration had continued at the same rate for another 10 years it would have militated seriously against the general efficiency and strength of the piles.

After the withdrawal of the piles from the staging structure across the northern opening of the harbour, the material therefrom was transferred to the workyard, where opportunities existed for carefully examining the ironwork. The plaster cast taken from the surface of the piles, exhibited in the museum, shows the character, disposition, and general extent and arrangement of the pitting to which reference is made.

In connection with the carrying out of the Graving Dock—an extensive work of itself—a cofferdam was required across the entrance. This consisted of jarrah main piling and half-timber sheeting, which was driven between November 1899, and August, 1900. This dam was periodically examined with a view to ascertaining the destructive effect of the teredo on the jarrah timber, which was noticeable particularly between wind and water. In about 2½ years the half-timber sheet piles became practically eaten through, and it was later found necessary to drive, on the inside of this sheeting, poling boards, also of jarrah, to retain the puddle hearting, which was being washed out by the action of the sea. The cofferdam was removed upon the completion of the work

six years after being driven. During the process of drawing, the half-timber sheeting parted between wind and water, where it had been badly attacked by teredo. The main piles were also found to have been very severely attacked, some of them being almost completely eaten through.

Eighteen jetties were erected in front of the coaling depot, in the positions shown on the plan. These jetties consisted of tiers of concrete cylinders, sunk as rings, to a secure foundation, and subsequently filled with concrete-in-mass. In connection with these jetties it became necessary to provide certain fendering, in order to prevent chafing of the concrete in the main structure of the jetties by the sides of the comparatively small coaling barges employed at this port. After careful enquiry and consideration it appeared that teak, which is the timber largely used in Ceylon and is rightly considered to be one of the most suitable materials employed in that locality, would constitute the best timber for use in connection with fendering. Experience, however, showed that the teak in the lower walings in these jetties, and the strengthening struts at the back of the same, were so destroyed by the action of teredo that they had to be removed and replaced by others, composed of ferro-concrete, after being only about 2 years in the work.

The use of teak was retained in the vertical fenders in connection with these jetties, which have to be removed, on an average, once in $2\frac{1}{2}$ years, partly by reason of the ravages of teredo, but mainly on account of the abrasion caused by the rise and fall of the small coaling lighters lying alongside these works, which are continually rubbing against them due to "lipper" on the surface of the water within the large enclosure forming the harbour, produced by "wind lop."

Photographs of specimens of worm-eaten timber taken from these jetties are appended, Plate XXVIII., and specimens of the destruction by the teredo of the walings and fenders have been deposited in the museum.

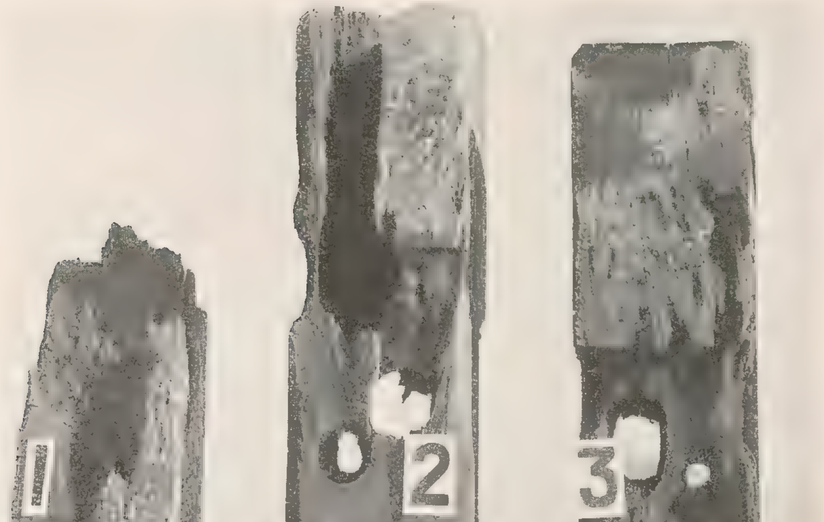
It may be remarked as a matter of interest, that during the carrying out of the main works, in the early stages of the operations, a flat-bottomed rail of Vignoles section was removed from the bed of the harbour, which, in all probability, had fallen overboard when discharging rails long before the commencement of the works. This rail, which was rolled from piled iron, consisting of fibre and crystal, showed in its head laminations of these two classes of material, and clearly demonstrated the fact that the crystal, or harder portion of the iron, was very much less reduced by corrosion, and wastage due thereto, than the richer and more fibrous portion, the crystal standing up above the fibre longitudinally along the surface of the rail head to the extent of $\frac{1}{8}$ inch to $\frac{1}{4}$ inch.

The whole of these works have been carried out departmentally, without the intervention of a contractor; the consulting engineers were Messrs. Coode, Son & Matthews.

PLATE XXVIII.

COLOMBO HARBOUR.

View No. 1.

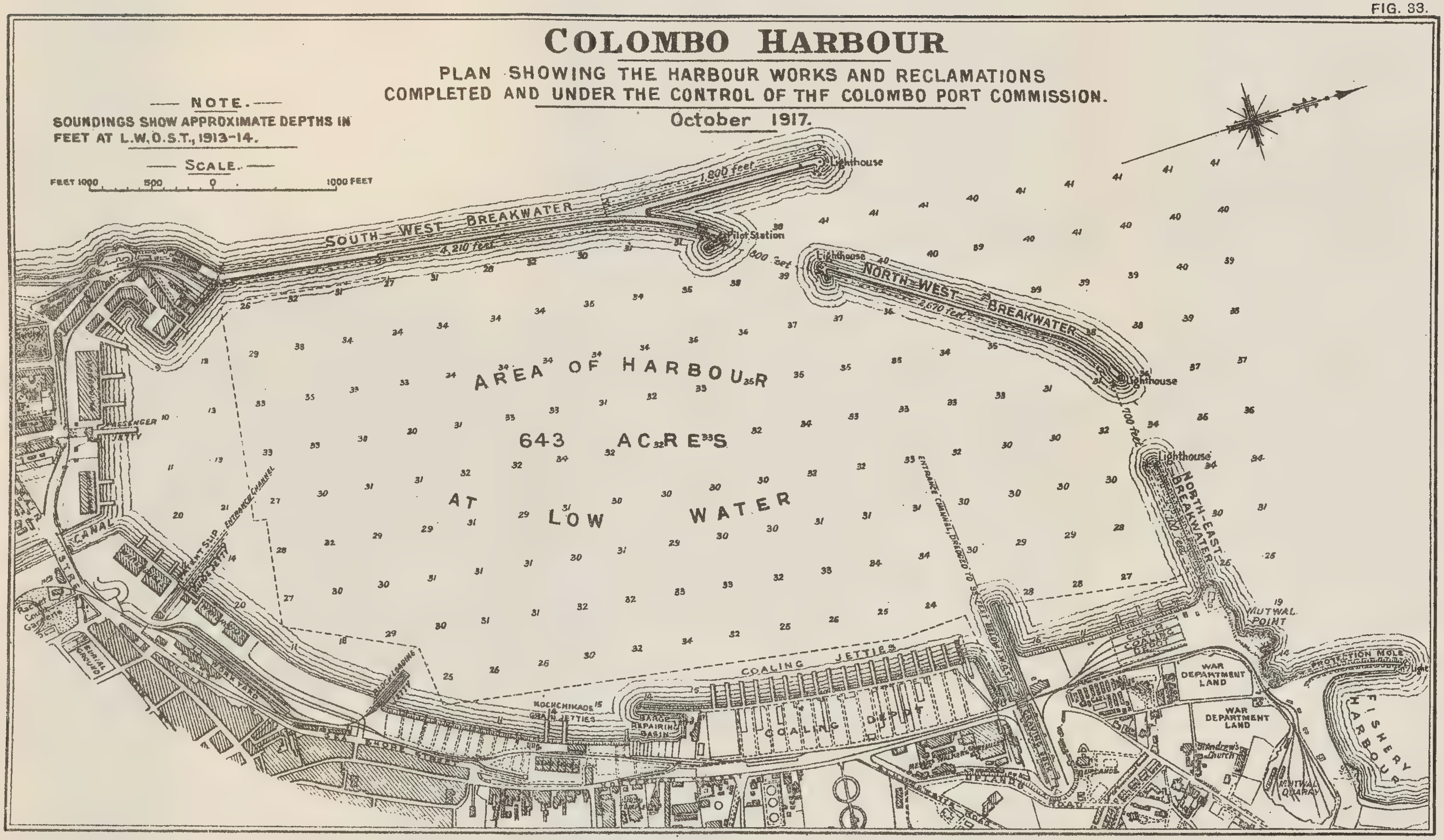


View No. 2.

SPECIMENS OF WORM-EATEN TEAK.

Nos. 1, 2, 3.—Fenders of coaling jetties. 2 years between wind and water.

FIG. 33.


COLOMBO HARBOUR
PLAN SHOWING THE HARBOUR WORKS AND RECLAMATIONS
COMPLETED AND UNDER THE CONTROL OF THF COLOMBO PORT COMMISSION.
October 1917.
NOTE.
SOUNDINGS SHOW APPROXIMATE DEPTHS IN FEET AT L.W.O.S.T., 1913-14.
SCALE.
FEET 1000 500 0 1000 FEET
SOUTH-WEST BREAKWATER
1,800 feet
4,210 feet
Lighthouse
Pilot Station
800 feet
NORTH-WEST BREAKWATER
2,670 feet
Lighthouse
700 feet
NORTH-EAST BREAKWATER
AREA OF HARBOUR
643 ACRES
AT LOW WATER
PASSENGER JETTY
CANAL
COALING JETTIES
COALING DEPOT
BARGE REPAIRING BASIN
KOCHCHIKADE GRAIN JETTIES
WAR DEPARTMENT LAND
St. Andrew's Church
MUTWAL POINT
PROTECTION MOLE
FISHERY HARBOUR
MUTWAL QUARRY

KARACHI.

By W. H. NEILSON, B.A., B.A.I., M.Inst.C.E., Chief Engineer, Karachi Port Trust.

Old Angle Bracing removed from Berth No. 7.—This berth is of the screw pile type, with 6-inch steel piles and angle bracings and is only subject to the action of sea-water. No fresh water, except at occasional intervals, enters the Port of Karachi. Tides rise 9 feet 3 inches in the springs and about 6 feet in the neaps. The bottom of the angle bracing is at datum, namely 0·00 L.W.O.S.T., and the top is at + 12·00, so that the lower portion is almost continuously in the water. The bracing has been in the jetty structure for 30 years and was recently taken out. All the iron work of the jetties is scraped and painted once every two years, but the painting is not taken below a level of + 8·00, as below this level barnacles and small molluscs attach themselves to the metal and appear to afford a good protection against quick deterioration. This layer of barnacles, etc, varies from ¼ inch to ½ inch in thickness all round.

Size of bracing	6 by 4 by ½ inch.
Length of bracing	19 feet.
Weight of bracing when put in . .	305 lb.
Weight of bracing when taken out of structure, including weight of attached barnacles	290 lb.
Weight of bracing after thoroughly scaling and cleaning	238 lb.

The loss of steel was therefore 67 lb., or say 22 per cent. The major portion of this loss occurred at the attachment to the pile cap where it was not possible to cover the work properly with paint, and also at the point shown on Plan at A, see Fig. 34, where it was exposed to the air and sea-water alternately.

The appended details show the position of the bracing and also give sections of the angle iron sawn in two places. The areas are as follows:—

Area of angle when new . .	4·750 square inches.
,, ,, at A . . .	2·88 ,, ,,

This shows a loss of 40 per cent.

MADRAS HARBOUR.

By the Hon. Sir FRANCIS J. E. SPRING, K.C.I.E., M.A.I., M.Inst.C.E., Chief Engineer, Madras Port Trust.

Existing Structures.—I may explain that at the port of Madras, besides the breakwaters made of concrete blocks capped with mass concrete, as described in the Proceedings of the Inst. C. E., papers Nos. 3964 [1] and 4012,[2] there are not many structures likely to throw much light on the

[1] Minutes of Proceedings Inst. C.E., Vol. cxc., p. 89.

[2] *Ibid.*, Vol. cxciv., p. 240.

matters forming the subject of your Committee's investigations. The only structures of any value for the purpose in view are the following:—

(a) An old screw pile pier with timber deck, now dismantled, some 50 years old;
(b) Three more screw-piers, not over 10 years old when dismantled, with steel decking beams and timber planking;
(c) A timber wharf now about 14 years old;
(d) Some 4,000 lineal feet of ferro-concrete wharfing, as described in Inst. C. E. paper No. 4012.

As regards pier (a) the available evidence is as follows:—8-inch screw piles were found after a life of about 50 years to have corroded to 7 inches diameter, and 6-inch piles to 5 inches, with occasional deep pit holes. The corrosion in question all occurred over sea-bed, the original rolling-mill bloom being often found on the uncorroded parts below sea-bed level.[1] Within tide-range, piles more exposed to the rubbing of boats and lighters unloading at the piers had worn down 2 to 3 inches on the exposed sides. The cast-iron screws, at from 10 to 20 feet below sea-bed, were found unaffected, except that these had always corroded fast on to the 6-inch or 8-inch piles, and had to be broken off when it was desired to separate them. The jarrah, or teak, timber beams and planking forming the deck of this pier showed no more than the usual degree of deterioration—that is, the proximity to sea-water did not seem to affect them specially.

The structures (b) had hardly stood long enough before being dismantled for the 4-inch and 5-inch piles composing their substructure to give signs of much deterioration. Their steel deck-beams, however, were found to have deteriorated very rapidly. For example, a deck beam weighing originally 1,628 lb. was found to weigh only 663 lb. after 8 years. The beams near the shore that were continuously splashed by the surf were found to go very much more rapidly than those further out to sea, and therefore not so continuously splashed. I would never again use steel beams in the decks of such structures.

The wharf (c) was built originally with "turpentine" piles and decking, a New South Wales timber professing to be teredo-proof—at least when the bark is intact—and though still more or less in use after 12 years, the piles have practically gone. Indeed, after 6 or 7 years they were no longer safe for the locomotives and similar loads which safely ran over them originally. But the decking, capping and transverse beams above water are still quite good.

Reinforced Concrete.—Next as regards reinforced concrete:—This class of work is not found to deteriorate except when it has been cracked by lighters knocking against it. Ordinarily, $1\frac{1}{2}$ inch of concrete between steel and water seems to be good enough. In sheltered basins it gets covered within a few months with dense layers of oyster and mussel shells which do much to save its surface from wear and tear.

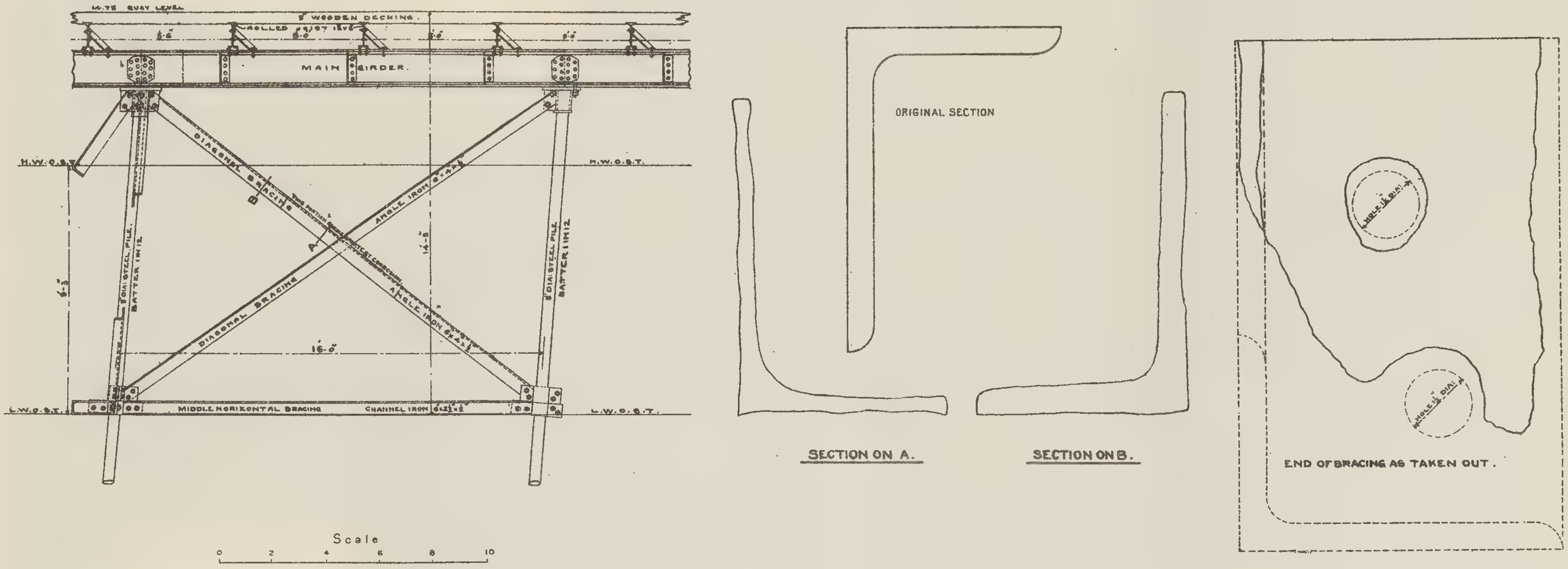
With respect to the suggestion that experiments should be made, I

[1] This was a wrought-iron structure, *not* steel.

FIG. 34.

KARACHI.

Details of Iron Jetty with Sections to show corrosion.



MADRAS HARBOUR.

Statement showing the differences of Original and Corroded Sections of the following H Beams.

Original Sections of Beams.			Present Sections of Beams.						
Sizes of Beams.	Weight per foot in lb.	Total weight in lb.	Sizes of Beams.	Weight per foot in lb.	Total weight in lb.	Time in use.	Level of Pier.	Total loss in weight.	Remarks.
feet. ins. ins. in. 30 × 10 × 6 × 0·40 (thickness of webs)	42	1,260	feet. ins. ins. in. 30 × 10 × 6 × 0·20 (thickness of webs)	23·80	714	8 years	+10·00	43 %	Low Level Jetty (Deck beam).
37 × 12 × 6 × 0·40 ,,	44	1,628	37 × 12 × 6 × 0·20 ,,	17·92	663	,,	+12·00	59 %	D. I. & N. D. I. Pier (Deck beam).
37 × 16 × 6 × 0·55 ,,	62	2,294	37 × 16 × 6 × 0·23 ,,	41·13	1,522	,,	+10·00	33 %	Low Level Jetty (Cross beam).
32 × 18 × 7 × 0·55 ,,	75	2,400	32 × 18 × 7 × 0·36 ,,	60·70	1,943	,,	+12·00	20 %	D. I. & N. D. I. Pier (Cross beam).

Q

do not think that any useful purpose will be served by such experiments being made in Madras; for no experiment could have as high a practical value as that derived from the above large-scale experience. Teak and jarrah are the only available timbers worth experimenting on in the sea-water of these latitudes. No trial has been made here of sheathing such structures with copper, which undoubtedly would be stripped off and stolen. Concrete could of course be used for sheathing, but it would probably prove cheaper to renew the timber every few years.

It is, I consider, well worth the while of your Committee to look up what I said in my Inst. C. E. Paper No. 3964,[1] about the preservation of corrugated iron roofs, under the head "sheds." The method there explained has now been in use over a considerable acreage of corrugated-iron roofed shedding for fully 10 years, with complete success. In the warm, tropical, salt-laden air, this class of roof covering would not have had a life of more than four or five years, but for the use of the Portland cement wash, which is renewed at suitable times yearly.

Finally, to deal with the remaining points in your circular letter. Freshwater discharges do not affect the degree of salinity in Madras. All city sewage has now been cut off from the harbour. The sea temperature is ordinarily between 70° and 80° F. There is no chemical effluent.

In the replacement of certain fender piles in the face of a certain 8-inch solid screw-pile pier, used by vessels needing up to 30 feet of water, some 15-inch square ferro-concrete piles were tried, but with disastrous results; for they went to pieces at once when, as the result of "range," or of accidents in approaching or leaving the berth, ships pressed against them, thereby cracking them and letting sea-water in to the reinforcement. These piles had to be removed and jarrah piles were again substituted.

As regards concrete in blocks and in mass I can add nothing to what has been said on this subject in my Inst. C. E. Paper No. 4012.[2] On being removed after 25 or 30 years, submarine blocks have been found to have suffered practically nothing beyond, perhaps, having the corners rubbed off and so on.

I cannot say that I think much will be gained in the way of scientific information—at least, in Madras—by inaugurating the experiments suggested in your letter.

I have had no experience of tar-coated concrete, and think it unlikely to be effective in exposed tropical salt water, though conceivably it might be useful in the Thames, Humber or Mersey. Moreover, after being once laid on, it could never be renewed below water. Also, I think it probable that—until, after some 2 or 3 years, it had been dissipated—it would prevent the very valuable growth of shell-fish previously referred to.

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[1] Minutes of Proceedings Inst. C.E., Vol. cxc., p. 89.
[2] *Ibid.*, Vol. cxciv., p. 240.

SINGAPORE AND PENANG HARBOURS.

By Sir J. R. NICHOLSON, C.M.G., Chairman of the Harbour Boards at Singapore and Penang.

Timber.—The wharves of the Board at Singapore, until the year 1909, consisted entirely of timber pile construction. They were commenced in 1865, and at the time when their demolition was undertaken in 1909, to clear the site for the new scheme of extensions and reconstruction, they were 9,560 feet long, with an average width of 60 feet and a depth of water alongside of from 18 to 40 feet L.W.O.S.T., with a tidal range of 9 feet. The cost of their upkeep, due to the destructive agency of marine borers and insects, became so excessive that it was imperative to adopt a more durable material of construction for the new works.

The piles of the earliest construction were of billian and merebaw, two extremely hard woods, which have been practically unobtainable of the necessary length or in sufficient quantity for many years. All piles used in later times were of ballow, a hard wood, weighing about 65 lbs. per cubic foot, but as this timber is now difficult to obtain of good quality, an inferior class of the same timber was used for replacements and repairs during the few years preceding reconstruction.

The teredo is exceedingly destructive at Singapore. It attacks practically all timbers, the softer kinds being very rapidly destroyed. Some of its borings are fully $\frac{3}{4}$ inch in diameter, even in the harder woods.

Three samples are sent of a ballow pile, driven 14 years ago, and one of a diagonal strut, originally 12 inches by 6 inches, which clearly show the working of the teredo and its effect. It will be noticed that nearly all the holes clear each other by a thin dividing partition, and they very seldom join. Piles which appear almost sound on the outside, show, when cut, very little of the original timber section remaining. Of the local timbers, billian and merebaw have the greatest resisting power to the teredo. A pair of dock gates, after removal, having been in use about 40 years, showed practically no signs of the teredo in the billian heel and meeting posts.

A half-tide fender of greenheart, capped with a ballow rubbing face 6 inches thick, has been used on the new concrete quay construction. A section of this has been in use now for 9 years, and although the ballow is attacked, the greenheart is practically free, as far as outside observation shows. When first put in the ballow rubbing face was fixed to the greenheart by oak trenails, but these so rapidly deteriorated from climatic causes that they were replaced by heavy steel coach screws.

No preservative composition has been tried in Singapore. It would certainly not be effective with the harder timbers, and its effect on the softer kinds would not be sufficiently durable to act as a deterrent against the teredo attack. Piles have been sheathed with Muntz metal, yellow metal and zinc, but, owing to the deterioration of these materials, they have not proved very effective, and their use has long ago been abandoned. Some piles have been cased with concrete, but, unless the structure in which they are used is perfectly rigid, the practice is not worth the expense. Piles driven with the bark on have proved the most economical

protection against the teredo; indeed, some of them are still effective after 12 years' service, although they are of an inferior quality of ballow. Jarrah has been used for boat step treads and wharf decking, but it is much inferior to ballow for both purposes. It is quickly attacked by the teredo, and does not stand heavy traffic; when subject to tropical rains and sun, its binding nature seems to give out and it can be scraped up by the foot into a bundle of fibres.

The limnoria is also very destructive, as will be seen by the outside of the samples sent.

Iron and Steel.—In Singapore and Penang there are considerable lengths of wharves constructed of iron and steel, the former material being used as cylinders filled with concrete, also as built up screw piles, steel being used for the solid screw pile construction. Our experience is that the best preservative for both constructions below high water-mark is the growth of shells which cover the work. Where this growth has been removed, it invariably comes away with the scab adhering, as will be seen from the sample which was taken from work finished 12 years ago. In very few cases has pitting been noticed when the shells were removed. Where pitting occurs, the hole is filled with a black powder. Corrosion is most noticeable on the edge of angle irons, to which the shells do not to any extent adhere. The corrosion has not been great here, but sufficient to show the laminations of the material.

Experiments made with different preservative compositions applied to steel plates and joists placed at half-tide level have shown that the best results, after 12 months, are obtained by a coating of hot tar, dusted with Portland cement. A better way of applying this mixture, and in standing structures the only practical way, would be to mix the materials before application. Wooden decking should be laid on steel work, so as to allow as much drainage and ventilation as possible, and all bearing timbers should be laid over a well-tarred preparation.

The chipping hammer is a dangerous tool in the hands of the ordinary labourer. The use of scrapers is a more tedious process, but the result is more satisfactory.

I send some photographs of the old wooden wharves, which clearly show the destruction of the teredo, see Plates XXIX. and XXX.

SINGAPORE.

By M. F. G. WILSON, M.Inst.C.E., Member of the Special Committee.

The writer has on several occasions visited Singapore in connection with works being carried out there under the direction of his firm. Singapore is about $1\frac{1}{2}°$ north of the Equator, so that the following remarks relate entirely to timbers in tropical waters. The teredo is extremely active and also the limnoria, and the "life" of most timbers is limited to a very few years.

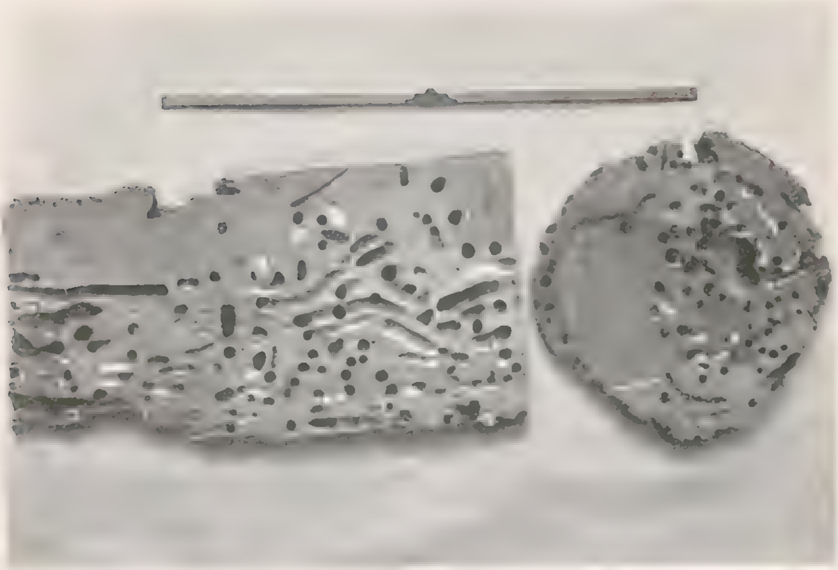
In 1912 a number of staging piles of Australian blue gum and Oregon pine, which had only been about 18 months in the water, were examined and found to be practically eaten through by teredo at a level of about

SINGAPORE.

VIEW OF EAST WHARF AT LOW WATER SHOWING DECAY OF BRACINGS OF BALLOW, LOOKING EAST.

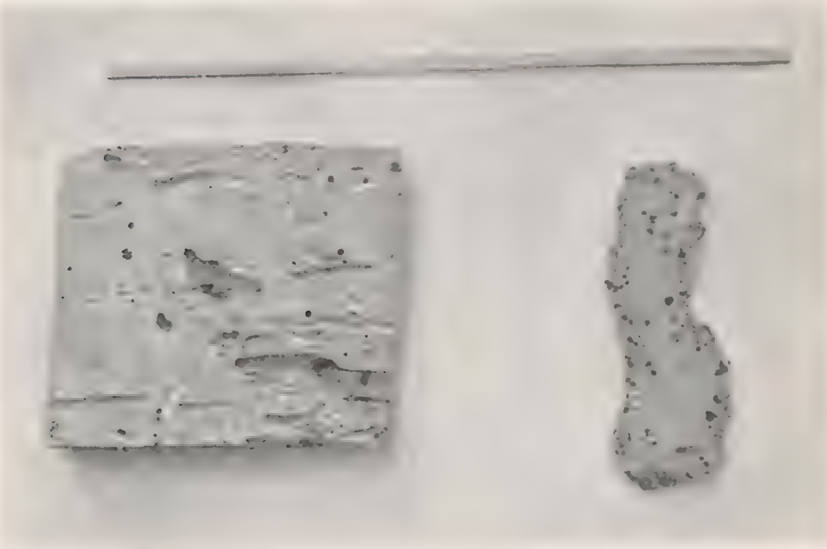
VIEW OF EAST WHARF, LOOKING WEST, SHOWING DECAY OF BRACINGS OF BALLOW.

SINGAPORE.



SECTIONS OF A PILE IN EAST WHARF SHOWING TEREDO ACTION.

Original section of pile about 13 inches × 13 inches. Length of specimen about 2 feet, cut out of pile between levels of 3 feet 6 inches and 5 feet 6 inches above L.W.O.S.T. Holes range up to ¾-inch diameter. Description of timber, Ballow. Age of timber, piles driven 14 years ago.



SECTIONS OF HORIZONTAL BRACING OF EAST WHARF.

Original section 12 inches × 6 inches. Situation, about 2 feet 6 inches above L.W.O.S.T. Holes range up to about ⅜-inch diameter. Timber, Ballow.

SINGAPORE.

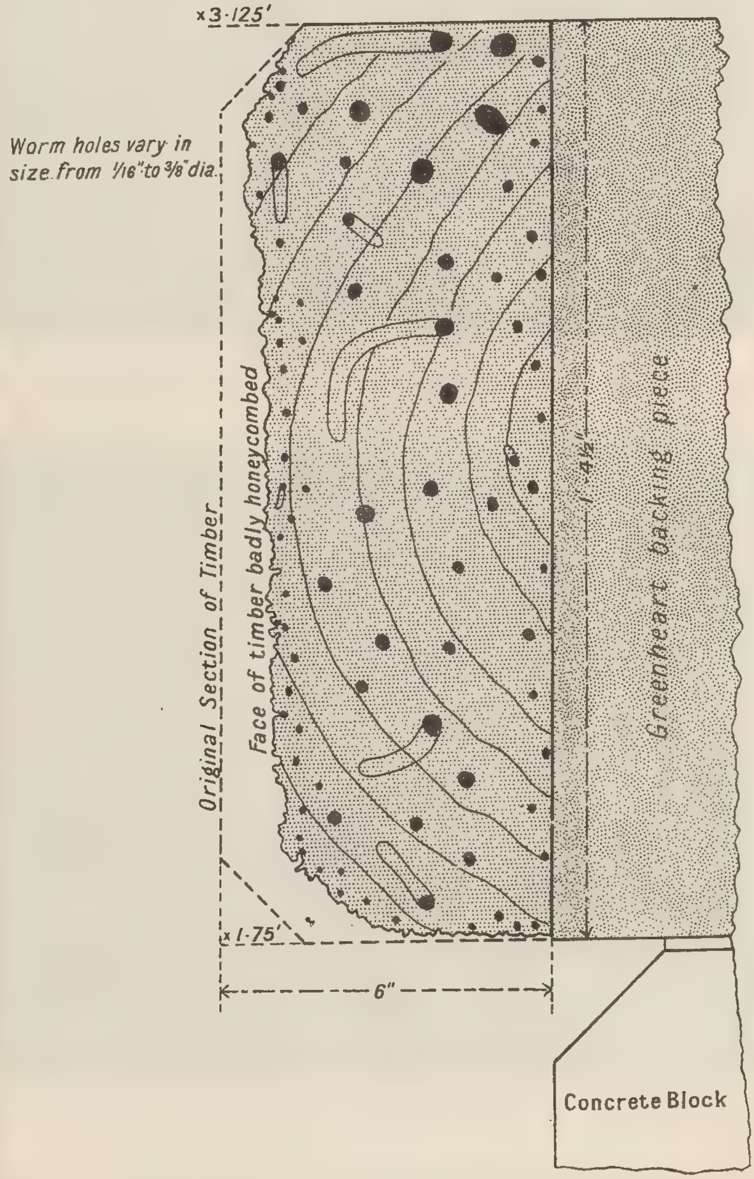
Tanjong Pagar Dock Works.
Ballow fendering at knuckle on West Wall of Entrance Channel, Graving Dock, August, 1917.

Tanjong Pagar Dock Works.
Ballow rubbing piece on West Wall of Entrance Channel, Graving Dock, August, 1917.

FIG. 35.

SINGAPORE.

Section of Ballow Rubbing Piece to show teredo attack.



2 feet above low water. There were no surface indications of worm action above the level of H.W.N.T., nor lower than 3 to 4 feet below low-water spring tides. Spring tides rise about 9 feet, and neap tides 6 to 7 feet. Some Oregon piles 16 inches by 16 inches, which had been 8 months in the water, as temporary staging piles, and had received two coats of tar previous to driving, were found to be perfectly sound, while native hardwood piles were completely eaten through by teredo in 15 months.

The only timber which appears able to offer any satisfactory resistance to the teredo in Singapore is greenheart, and this timber has been used to a considerable extent for fendering. In some cases ballow, the best local hardwood, has been attached to the face of greenheart backing timbers, to form rubbing pieces.

Mr. D. Paterson, Resident Engineer, has recently made a thorough examination of the whole of the works, and has furnished the writer with a report, from which the following are extracts :—

" *Timber fendering, etc.*—All backing pieces on the various works here, all fendering at the harbour works, and the vertical and two lower horizontal fenders on the wrought iron cylinder construction are of greenheart, and all appear to be standing very well.

" Some of the greenheart rubbing pieces have split for about 18 inches from the bottom, and where the ends of backing pieces are exposed the timber has split for, say, 9 inches and is decayed at the heart. These are the only places where I have observed decay, and there are no signs of worm action. The timber which has been longest in the sea was fixed about 8 years ago, and it all appears to be in very good condition.

" *Ballow* timber, which has only been in the water about 4 years, shows a good deal of worm action though it is not attacked uniformly, the low horizontal fendering on the outer portion of the walls, fixed at a level of about 2 feet 6 inches above low water, is all honeycombed on the face and lower edges, and where in some cases a beam of timber is badly eaten away, its neighbour is practically untouched. In ballow the decay and worm action seems to commence about $+5{\cdot}00$ level (*i.e.* 5 feet above low water) and extends downwards to $+1{\cdot}00$, being worst at the lower level. There is no fendering below this level, but as the Oregon pine staging piles here were attacked by worm down to ground level, probably the same would apply to ballow. The life of ballow timber in the sea appears be from 4 to 6 years.

" I enclose a copy of a drawing showing a section of ballow rubbing piece. This shows the most badly holed piece of timber I could find, Fig. 35.

" I tried to get some photographs taken showing the state of the fendering, but as they had to be taken from a boat a small camera had to be used, and the results are disappointing, see Plate XXXI.

" Compressed oak trenails were used for securing the rubbing pieces to backing timbers. In the low horizontal fendering they are badly decayed, apparently from a species of wet rot—in some cases hardly one trenail is left, and it is possible to push a foot-rule right to the bottom of the hole in the greenheart backing piece, the rubbing piece being retained

in place merely by the iron spikes which were used to hold the rubbing piece in position while it was being put on."

With regard to the preservatives for timber in sea-water, nothing really effective seems yet to have been discovered, where the worm is active. At Singapore, the contractors tried various patent paints and other substances for stagings, etc., but without any good result. In the case of several godowns erected by the Harbour Board and carried on piles driven in the water, the piles were cased with fine concrete to a level a little below ground level, and this appears to have been very satisfactory. The writer could not ascertain accurately how long they had been in use, but certainly for a number of years. The ground where the piles were driven dried at low water, so that it was not necessary to carry the casing below that level.

Iron and Steel.—In the works already referred, to a large quantity of steel and wrought iron was used; notably in the construction of a deep-water wharf which was constructed of wrought-iron cylinders, filled with concrete, having a superstructure of steel girders covered with steel trough decking, finished off with a concrete surface. Galvanized wrought-iron ladders and railings were also placed at various places throughout the works as required. The following extracts relating to the condition of the steel and iron are taken from the report of the Resident Engineer already referred to:—

"*Wrought-iron Cylinder Construction.*—The western portion of this wharf has been completed for about 7 years, the inner portion forming the west side of the wet dock entrance was completed 3 to $3\frac{1}{2}$ years ago.

"The steelwork in girders, troughing, etc., is in very good condition generally, and is painted when any rusting is observed, say once in 2 to 3 years.

"On the wrought-iron cylinders, struts, wales, etc., there is a coating of small oysters, barnacles and other shellfish and marine vegetable growth from the level of $+5{\cdot}50$, or about the level of H.W.O.N.T., down to ground level; this coating completely covered the metal, being thickest about the area between $+2$ and -15 feet, and gradually diminishing down to the ground level.

"The coating adheres strongly to the metal and on removal by the chipping hammer or scraper it comes away accompanied by a fairly hard black scale from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch thick, leaving a dull black surface of practically bare metal.

"I collected some of this scale and find that, on exposure to the air for a day or two, it turns a brownish red, and as on testing it with hydrochloric acid it gives off sulphuretted hydrogen, I assume it to be, at least partly, ferrous sulphide.

"About the level of $+5{\cdot}50$ there is some rusting on the western and older portion of the work, but nothing that could not be prevented by chipping and painting once, say, in 2 years. I examined several places on the cylinders and sleeves, both above water and down to ground level, and found very few signs of corrosion, the edges of all plates when scraped were clean and sharp, and rivet heads were of full size. There are a few small irregularly shaped pittings on the upper surfaces of struts, but only

to the depth of, say, $\frac{1}{16}$ inch, and a few rivet heads are slightly reduced in size.

"The worst corrosion observable is on the lower fender brackets near L.W.O.S.T. at the western end of the wharf, where in some cases they have had the coating of shells removed from the front edges, probably through small craft, ships' fenders, etc., coming into contact with them, and when bared the remainder of the bracket shows considerable corrosion. On the front edge the metal has been reduced to $\frac{3}{8}$ inch from its original thickness of $\frac{5}{8}$ inch, the angles also are wasted to a small extent—the fibres of the metal showing clearly. Nothing has been done below the level of + 5·50 in the way of painting or tarring the metal and the coating of shells, etc., is left undisturbed.

"The galvanized ironwork in many cases is not standing well, all boatstep handrails are badly rusted, and also the lower portion of all ladders which have been more than 2 years in the water.

"On the quays and sea faces of the piers the lower bands securing the fendering are all in very good condition: on removing the shells the galvanized coating appears quite intact, but the centre bands, which are above the shell level, and even the upper bands are badly rusted. Inside the tidal basin the only corrosion observable is on the centre bands, which are badly rusted. The rusting of the upper bands on the sea faces of the piers and quays is evidently due to their being wetted occasionally by spray from waves striking the wall at high water, as there is no sign of rust on the corresponding bands inside the basin, where the water is always smooth. The excessive rusting of the boatstep handrails is no doubt also due to the same cause, as even on calm days there is always a certain amount of wave motion and splashing against the steps.

"All galvanized work above cope level in handrailing, stanchions, etc., is in excellent condition."

The writer was himself quite recently in Singapore on a visit of inspection to the works, and he can entirely endorse Mr. Paterson's observations, and was much struck by the preservation of the material which appeared to be afforded by the coating of shells and marine growth alluded to.

Reinforced concrete has been used to a considerable extent in connection with the works at Singapore, for deep-water wharves and piers. The writer, during his recent visit, made a careful examination of this work and is able to state that he found it all in most excellent condition and he could discover no signs of rust or deterioration. It should be noted, however, that this work has only been constructed within the last 5 years. The following extract from the Resident Engineer's report may be of interest:—

"*Reinforced Concrete Work.*—Main Wharf G-H. This wharf was tarred about 4 months ago all over and above the level of +4·00 on the wharf and + 4·75 on the gangways, with the exception of the upper surface of the decking. The work is in excellent condition, and there are no signs of moisture or "sweating" on the surface of the concrete, though the weather at present is of the usual hot and showery description

generally experienced here. The coating of tar seems to have sealed up the pores of the concrete very satisfactorily, and it has also closed the fine hair cracks which were visible in the beams over the trusses.

"The cracks in the decking running across the wharf at about $\frac{2}{3}$ of a bay were in the worst cases cleaned out and grouted up recently, but they all showed signs of efflorescence, and in one or two cases bear traces of moisture on the underside of the decking, though no rust stains can be seen. Corresponding with these cracks there are a few hair cracks just visible in the deck beams, but the tar has sealed them up and they show no signs of movement.

"The Harbour works here generally, except for some settlement cracks at the South Pier Head and at the roots of the Piers, are all in excellent condition, and the surface of the concrete above tide level is quite dry. A few signs of efflorescence are observable at cracks where evidently a day's work ceased, but there are no rust stains. All the slight open joints and places where the stirrups were badly covered by the concrete, have been made good by the Singapore Harbour Board."

The proportions of the reinforced concrete consisted throughout of 1 part of Portland cement to $1\frac{1}{3}$ part of sand and $2\frac{2}{3}$ parts of granite, broken to $\frac{3}{4}$ inch mesh. The small material derived from the crushing of the granite was left in, as tending to render the concrete more solid and watertight.

It appears to the writer that with regard to reinforced concrete in sea-water, the following are two salient facts. (1) Deterioration due to corrosion of the reinforcement seldom takes place below the level of between half tide and H.W.N.T., and (2) if the concrete be made watertight, corrosion will not take place at all.

It would be of value to determine the true cause of the immunity from corrosion below the level indicated, and whether such immunity can be relied upon, *i.e.*, may reinforced concrete, properly proportioned, mixed, and deposited with ordinary care, be considered perfectly safe from the effects of corrosion below a given level, to be determined in relation to the tide? At present one frequently sees general and rather vague statements such as, that below a given level the concrete is constantly wet, and the pores are closed by the alkaline salts in solution in the sea-water that enter into chemical composition with the lime of the concrete, etc.

With regard to watertightness, suitable proportions and very careful mixing and depositing will no doubt effect a great deal, and subsequent coating with tar or other material may effect the rest that is required to produce permanently sound work. If, however, by the addition of some ingredient, or by some other means during the mixing of the concrete, an absolutely watertight material could be produced, which would not be entirely dependent upon special excellence in mixing, etc., and subsequent coating, it would, in the writer's opinion, be the best solution of the question.

KOWLOON, HONG KONG.

By SOMERS H. ELLIS, M.Inst.C.E.

I REGRET that my previous Report on the condition of timber at Belawan, Sumatra, was sent to you before receipt of your circular letter of 13th June, 1917, so that it may not be in quite the form you ask for.

With reference to a question in the latter, I have had no experience of concrete coated with tar, except in the case of the deck of a wharf at Shanghai. The annual application of tar to this surface, which is marked by transverse contraction cracks at regular intervals, appears not only to exclude rain water from the concrete, but to preserve the surface from wear, by forming a tough, non-friable skin.

I am proposing to coat other ferro-concrete structures with tar above mean-tide level, and I believe the application will be efficacious; but tar does not adhere well to new concrete. The structure should be exposed to the weather for several months before the tar is applied.

Timber.—In the cross-section of Wharf No. 1 (Fig. 1), printed with the Paper entitled, "Corrosion of Steel Wharves at Kowloon,"[1] vertical timber fenders, 12 feet long, 14 inches by 14 inches section, are shown on the face of the wharf. These fenders are of billian, or Borneo ironwood (*Eusideroxylon zwageri*), and were placed in position early in the year 1909. They are attached towards the lower end by bolts to the projecting wharf bracing of steel channels, the point of attachment being 2 feet 6 inches above L.W.O.S.T. and the bottom end of the fenders about 6 inches above L.W.O.S.T. Deterioration of the lower ends has now reached such a stage (after 8 years' life) that renewal is necessary.

Generally speaking, the heart of the timber has disappeared for a height of from 4 to 6 feet from its lower end, and one side has also been eaten away for a height of from 2 to 4 feet. This defective side may be either the outer one, or either of those adjacent to the face; never, except for a short length at the foot, the inner side, which bears against the concrete casing of the wharf pier. The remaining wood appears to be entirely sound and hard, and only shows traces of the teredo at its extreme lower end, so that the cause of deterioration to such a universal and marked degree is rather obscure. The only trace of decay in the remaining wood is the presence of a brown, powdery substance about $\frac{1}{8}$ inch thick, which adheres to the inside of the hollow. Probably deterioration is due to (1) attack by the teredo at the lower end (limited by the periods of exposure above water, only a brief time at each spring tide), and (2) decay, helped by the presence of the through bolt. Preventive measures might, therefore, consist in applying a covering of sheet metal to the lower end, and in adopting other methods of attachment which would eliminate the through bolt at any level below high-water line.

A sample of the lower end of a fender is being sent, together with a there piece of the same wood from above high-water level.

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[1] 'Minutes of Proceedings Inst. C.E., Vol. cxcix, p. 133.

Steel.—The bulk of the information contained in these notes appears in a Paper entitled, "Corrosion of Steel Wharves at Kowloon," read before the Institution of Civil Engineers in 1914, but the information given is supplemented by the results of later inspection.

During the years 1907–9 a series of steel wharves and jetties were constructed for Messrs. Alfred Holt & Co., owners of the Ocean S.S. Co., on the mainland side of Hong Kong Harbour. They are situated at the south-eastern corner of the Kowloon promontory, and are subjected to the action of alternating tidal currents, ranging up to 4 miles an hour. The water is salt and clear, and uncontaminated by sewage to any appreciable extent.

The structure entitled Wharf No. 2, which may be taken as typical of those constructed of unsheathed steel, is a projecting jetty, 250 feet long and 40 feet wide. It is formed of three rows of steel piles, 12 inches by 12 inches of 80 lb. H iron in section, braced above low-water level by steel channels, and it has a timber deck. The six outermost cross-rows of piles are braced under water also by a system of 6 inches by 5 inches rolled steel joist struts and 2 inches round steel diagonal ties, fastened to the piles by cast steel clips, see Fig. 36.

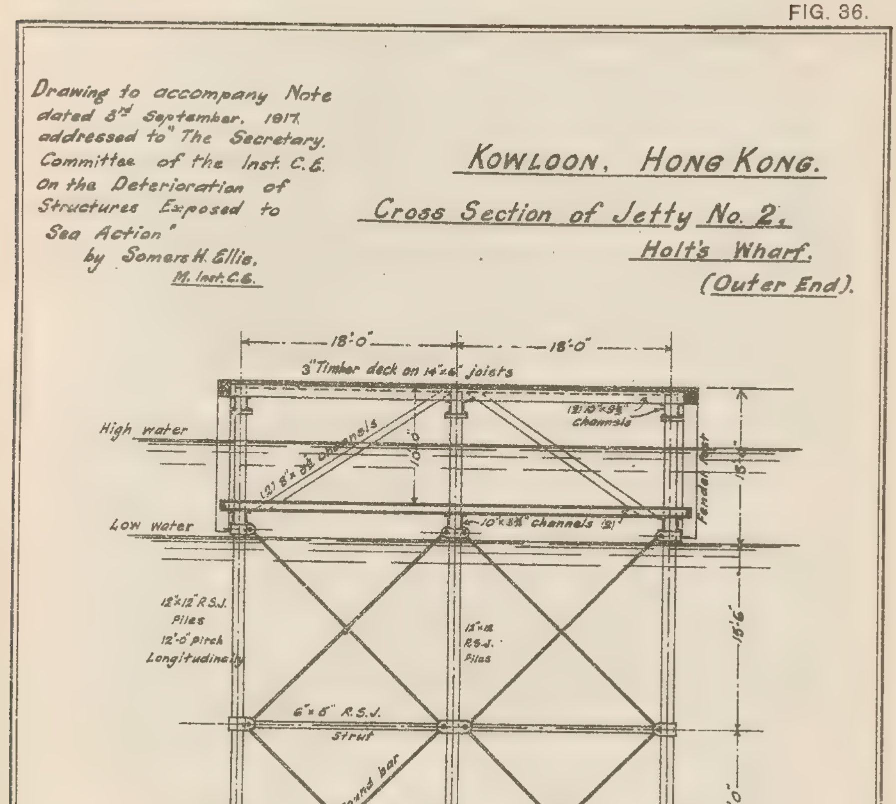
In July, 1910, 2 years after completion of the work, the writer inspected the structure at low tide, and found that a thick layer of shells and other marine growth had become attached to the metal below low-water level, and that the construction coat of paint had then almost disappeared. Above this level all steelwork had been scraped and painted annually, and was—as to this date it remains—in good condition. On scraping away the marine growth, it was discovered that the formation of pits had commenced on the surface of the piles, but not to any serious extent.

In April, 1913, a European diver was employed to ascertain the condition of the piles under water, and his report made it clear that this form of corrosion—viz., the formation of pits underneath the marine growth—had developed to a serious extent. Some of these pits were then $\frac{3}{8}$ inch in depth and $\frac{3}{4}$ inch to 1 inch in diameter, the form being oval. The writer personally inspected a pile on this jetty in August, 1913, and found the same condition existing at depths to 20 feet below water-level. The worst zone then appeared to be from 5 feet to 10 feet below L.W.O.S.T.

During the year 1915 the piles of the greater part of this jetty were encased in concrete, after being scraped and cleaned. Ten bays at the outer end were, however, left in their existing condition, and have during the last month been dismantled, as further development of the site involved their removal.

Examination of the structure when brought to shore showed that deterioration, due to this one cause—i.e., pitting of the metal under marine growth—had already, at the end of 9 years, reached the stage of seriously weakening the various members. The 6 inches by 5 inches joists forming the struts of the under-water bracing showed the defects most clearly, almost every piece being perforated, either through the flange or the web in one or more places; while the number of marked depressions

FIG. 36.



Drawing to accompany Note dated 3rd September, 1917, addressed to "The Secretary, Committee of the Inst. C.E. On the Deterioration of Structures Exposed to Sea Action" by Somers H. Ellis, M. Inst. C.E.
KOWLOON, HONG KONG.
Cross Section of Jetty No. 2.
Holt's Wharf.
(Outer End).
18'-0"
18'-0"
3" Timber deck on 14"x6" joists
channels
channels
High water
10'-0"
15'-0"
Fender
Low water
channels (2)
12"x12" R.S.J. Piles 12'-0" pitch Longitudinally
R.S.J. Piles
15'-6"
6"x6" R.S.J. Strut
Round bar
16'-0"
Surface of Ground
Sandy Silt
Surface of Rock
Scale
0 4 8 12 16 20 24 Feet

in the surface were such as to diminish seriously the section of the member.

The 2 inches diameter diagonal bracing showed the same pitting to a maximum depth of $\frac{1}{4}$ inch, and in holes up to $1\frac{1}{4}$ inch by $\frac{3}{4}$ inch in plan. Complete perforation was also found on some of the piles, through metal $\frac{5}{8}$ inch thick. The size of the pits varied from very small ones upwards, showing that the process of formation was continual, and that the number, as well as the size, of the pits tended to increase year by year. The cause of these depressions in the metal is still obscure. They are apparently due to the decomposition of some particular form of marine growth which evolves sulphuretted hydrogen, as many of the holes are found to contain iron sulphide (Fe S) in a black powder, which changes colour to red by oxidation on exposure to the air. Of actual rust there is very little trace. The larger depressions are generally found quite clean, and the abode of small crabs. Pitting is never, the writer thinks, found underneath oyster shells, which appear to protect the metal; neither do limpets nor barnacles appear to be the source of attack, but more probably some of those curious organisms which form a link in appearance between the animal and vegetable worlds.

The remedy appears to be a coating of concrete to steel structures in sea-water below L.W.O.N.T., above which level the metal can be maintained in good condition by annual scraping and painting.

The writer may mention that the circular, wrought-iron piles of Blake Pier at Hong Kong, mentioned by Sir William Matthews, K.C.M.G., in the discussion on the above-mentioned Paper, showed signs of similar pitting to a lesser extent when examined by a diver, and they have since then been encased in concrete.

NOTE BY M. F. G. WILSON, M.Inst.C.E.

(Member of the Special Committee.)

KOWLOON.

The writer has had an opportunity of inspecting the steel piles taken from the wharves at Kowloon, referred to by Mr. Somers Ellis in his Report. He saw a number of the piles which had been drawn, and they were badly pitted from a little above low-water right down to the ground level, the worst pitting occurred at about 12 feet below low-water. These piles had all been covered with marine shells and growth, which indicates that the incrustation cannot be regarded as an infallible preservative. It was stated that in each of the pitmarks, which were of oval shape, a small species of crab was found when the shells were removed, but it has not been determined whether or no there was any connection between the crab and the pitting. The worst pitting occurred in the web of the joists, the holes in some cases penetrated through the metal.

At Hong Kong, just opposite Kowloon, a small wrought-iron jetty of braced pilings was erected to the design of the writer's firm about 20 years ago. The upper portion was in good order, as it is scraped and coated periodically, but the writer was informed that below water-level, pitting,

as in the case of the Kowloon steel piles, was taking place. The piles are now to be cleaned and encased in concrete.

NOTES ON SHANGHAI, HONG KONG AND BELAWAN.

By SOMERS H. ELLIS, M.Inst.C.E.

1. *Shanghai.*—The river Whang-poo, at Shanghai, though tidal, is of fresh water, so that structures there are not included in the scope of the present enqniry. I may, however, refer to the employment of concrete at this place, as described on p. 233.

2. *Hong Kong.*—I may mention that several wharves in Hong Kong Harbour, from 25 to 30 years old, are constructed with piles of aranga, from the Philippine Islands, which timber has remained in a sound condition below water-level to the present time. Aranga (*Homalium*) is the only timber known in the Far East which almost entirely resists the attacks of the teredo and other sea pests, except the much harder and heavier wood known as luisin in the Philippines and bangkawang in Borneo (*Parinarium* sp., family *Rosaceæ*), which is almost impossible to saw or work.

I will have careful notes kept of the condition of some new wharves of a composite construction :—ferro-concrete piles and lower bracing, with bare steel superstructure and timber decking—which are now under construction, under my supervision, at Kowloon. The fenders for the new wharves will all be of aranga.

3. *Belawan, East Coast of Sumatra.*—During the 3 years from 1913 to 1916, three small wharves were constructed at this port under my supervision ; the situation being the swampy shore of a tidal river having brackish, muddy water, about three miles from the sea. These are described in a special report.

HALIFAX HARBOUR.

By C. E. W. DODWELL, B.A., M.Inst.C.E.

Anapolis Royal (pop. 2,000) is the oldest town in the province of Nova Scotia, as it was founded by Champlain in 1604. It has the distinction of being supposedly the first white settlement in America, north of the Gulf of Mexico, and it is beautifully situated at the head of the Anapolis Basin, on the south side of the mouth of the river of the same name, 130 miles west of Halifax. Between the years 1907–1914 the Department of Public Works of the Federal Government of Canada, under the direction of the Author, as District Engineer in charge, constructed a line of ten piers across the river, about a quarter of a mile above the town, with the primary object of preventing ice from drifting up and down with ebb and flood tide, and thus endangering shipping.

The width of the river at the site of the piers is, at low water, about 740 feet, and rather more than double this width at high water, and the design of the piers will indicate that they are not built solely as ice piers,

although they adequately serve this purpose, but they are also capable of being used as a sub-structure for a highway bridge. Had they been built solely for the former purpose, the piers would have been constructed from bottom to top of crib-work of round logs of timber, notched and well bolted at the intersections and filled with stone ballast, whilst if the ultimate use as a bridge had been intended they would have probably been built of solid concrete faced with granite. The adopted design is believed to be the most practicable combination of minimum cost with minimum permissible permanence and stability, see Fig. 37.

The lower portions of piers 1 to 5 inclusive are of creosoted square timber, 12 inches by 10 inches in section, filled with stone ballast The timber was treated with 14 lb. of oil per cubic foot. The upper portions of these piers and all of piers 6 to 10 inclusive are of concrete. The lower portions of piers 6 and 7 are encased in watertight cribs. built of squared spruce. The piers from 1 foot below to 5 feet above low water are faced or sheathed with birch (*Betula lutea*) plank 5 inches thick, and the corners are further protected by ½-inch steel cover plates.

The cribs were floated into position at low water, and the period of slack water being brief, great care and expedition were necessary to get them into correct position, and to hold them while they were sunk, as quickly as possible, by ballasting with rock, and by releasing the casks placed around them to give the buoyancy rendered necessary by the high specific gravity of the creosoted timber. Large anchors (about 3 tons each) 3 up and 3 down stream, on steel wire hawsers, adjustable with block and tackle, assured the final and correct positions of each crib.

The cement used in piers 1, 2, and 3 was "Lehigh," an excellent American Portland of the following qualities by test :—

Specific gravity	3·125
Fineness :—Passing No. 50 sieve	·16 per cent.
Passing No. 100 sieve	5·88 per cent
Passing No. 200 sieve	24·20 per cent.
Initial set of neat cement	1 hr. 34 min.
Full set of neat cement	4 hr. 49 min.
Percentage of water used	22
Average tensile strength of neat cement, 1 day in air and 6 in water	655 lb. per square inch
Average tensile strength 1 cement, 3 sand, 1 day in air and 6 in water	265 lb. per square inch

Chemical Analysis.

Silica	22·76 per cent.
Alumina and Ferric oxide	10·50 per cent.
Lime	61·60 per cent.
Magnesia	1·95 per cent.
Sulph. anhydride	1·65 per cent.
Loss on ignition	1·55 per cent.

The concrete in piers 1, 2, and 3, built in May and June, 1910, was composed of 1 volume of cement, 3 of clean, coarse, pit sand and 3 parts

of stone, broken to pass through a 2-inch ring. Displacers or "plums" of sound clean stone, not exceeding 2 cubic feet each, not less than 6 inches apart, or 9 inches from any face, were laid as the work progressed.

The specification provided that, as soon as the moulds had been removed, the sides and top of each pier were to be rendered with a cream of equal parts of sand and cement, trowelled to a smooth surface. On the top, and the upper 4 or 5 feet of the sides of the piers, this skin coat held pretty well, but below high-water mark it did not survive the first winter, owing to the difficulty in getting proper bond with the concrete that had been twice daily submerged.

The accompanying photographs show the effects of the 7 years' exposure of certain of these piers to

(*a*) the attacks of floating ice, and

(*b*) the alternate freeze and thaw to which the rise and fall of tide subjected them, see Plates XXXII. and XXXIII.

The author is regretfully aware that the value of this paper is small, in so far as it is an attempt to contribute to the evidence sought by the "Committee on the Deterioration of Structures Exposed to Sea-Action," owing to the impossibility of determining the proportions of the disintegration of the surface concrete of the piers herein described, due to these two influences respectively. The author's opinion is that frost has had the major influence, but opinions are not evidence. No concrete is absolutely impervious, however rich it may be, however well rammed, or however excellent the quality of its several constituents. At high tide, water penetrates its surface, if only to the depth of the fiftieth part of an inch. In a Nova Scotian winter the thermometer may be several degrees below zero F., and, as the tide recedes, the water in the concrete freezes, expanding as it does so. So long as the water in the surface of the concrete remains frozen, nothing appears to happen, but as soon as the tide again rises, and the skin water thaws, the surface film of concrete falls off in powder. This action going on twice in the 24 hours during the 4 or 5 months of winter, must inevitably result in the more or less rapid disintegration of the face of any concrete exposed to such influences. That abrading action of floating ice also contributes to the disintegration of the concrete, cannot of course be denied, for Plate XXXIII. shows a number of steps (of 1-inch round iron) in the end of pier No. 2, much bent by the blows from floating blocks of ice, which must therefore strike or rub against the pier with considerable force. The author's opinion is that,

(*a*) had it been possible to make the concrete absolutely impervious it would have suffered very little from ice action, and, that,

(*b*) had it been possible to prevent floating ice from touching the piers, they would have shown almost as much deterioration as they have suffered under the two influences of surface freeze and thaw, and the impact of ice. The maximum depth to which the concrete has been removed is about 15 inches, and this depth is reached in very few places only. The average depth is less than 6 inches, so that the actual diminution of bulk is inconsiderable. It is a singular, but unmistakable, fact

PLATE XXXII.

HALIFAX, NOVA SCOTIA.

PIER No. 3. FROM DOWN STREAM. 19th October, 1916.
Built 1909–10. Concrete, May and June, 1910.

PIER No. 1. FROM DOWN STREAM. 19th October, 1916.
Built 1909–10. Concrete, May and June, 1910.

HALIFAX, NOVA SCOTIA.

PIER NO. 2. FROM DOWN STREAM. 19th October, 1916.
Built 1909–10. Concrete, May and June, 1910.

that the disintegrating influences are slower in action now than they were during the first year or two. The causes of this retardation are as yet not quite clear, but the author believes one of them to be the formation, growth, or deposit of a coating or film of slime on the surface of the concrete (to which the blackness in the accompanying photographs is due), which protects it, to a certain extent, from :—

(*a*) the percolation of water,

(*b*) the freezing of the skin water while the tide is out,

or (*c*) the falling away of the disintegrated surface film of concrete, and the consequent exposure of fresh surface.

As much as 4 or 5 years ago the author fully expected to have been obliged to adopt some means of protecting piers 1, 2, and 3 from further deterioration, but it now seems that this may be deferred for another year or two.

Piers Nos. 4 and 5 were built in June and July, 1912, and with five years' exposure, they do not show nearly as much deterioration as piers 1, 2, and 3, though this may be due to other causes than the elapse of less time. The outer 9 inches in thickness of the concrete was composed of 1 of cement, 3 of sand and 1 of gravel, all the rest of the concrete being 1 cement, 3 sand, 2 broken stone and 2 gravel, displacers being used in the hearting. The cement was "White's" (English) and "Canada" (a Canadian article). The qualities of "White's" were :—

Specific gravity	3·073
Fineness :—Passing No. 50 sieve	·08 per cent.
Passing No. 100 sieve	1·44 per cent.
Passing No. 200 sieve	15·72 per cent.
Initial set of neat cement	1 hr. 32 min.
Full set of neat cement	3 hr. 37 min.
Percentage of water used	23
Average tensile strength of neat cement, 1 day in air and 6 in water	618 lb. per square inch.
Average tensile strength 1 cement, 3 sand, 1 day in air and 6 in water	287 lb. per square inch.

Chemical Analysis.

Silica	22·44 per cent.
Alumina and Ferric Oxide	9·14 per cent.
Lime	62·26 per cent.
Magnesia	1·98 per cent.
Sulph. anhydride	1·02 per cent.
Loss on ignition	1·75 per cent.

Several hundred tests of "Canada," neat cement, 1 day in air and 6 in water, gave an average tensile strength of 796 lb. per square inch, and a maximum of 900 lb. Briquettes of 1 cement and 3 sand gave at equal time an average of 330 and a maximum of 360, both classes of tests showing a very small margin between the maximum and minimum, thus indicating a cement of a very uniform and satisfactory character.

Piers 6 to 10 (the concrete portions) were built in December, 1913,

and January, 1914, they have therefore had only $3\frac{1}{2}$ years' exposure, and they show but little deterioration. The cement used was of three kinds, "White's," "Canada," and "Invicta," the last an English article of good quality, made by the West Kent Portland Cement Company (works at Burham and Aylesford), with tensile strengths of 640 and 306 respectively, neat, and 3 to 1, 1 day in air and 6 in water.

JAMAICA.

By J. H. W. PARK, B.Sc., M.Inst.C.E., Director of Public Works.

Timber used for sea structures in Jamaica.—For the smaller wharves and boathouses, outside of Kingston, local timbers are generally used. Those most commonly employed are Bastard Cabbage, Coconut, Mammee, Mangrove, Bullet, Wild Orange, Yoke Wood, Cashaw, Dogwood and Fiddlewood. A local "Greenheart" is also used.

Of the above yoke wood, bullet, dogwood and fiddlewood are regarded as the most durable, the last two being probably the best. The life generally appears to vary from 4 years for bastard cabbage to not less than 10 years for dogwood and fiddlewood. This is for unprotected piles. In many cases, where piles are coated yearly with tar between wind and water, dogwood and fiddlewood are stated to have lasted for 20 years.

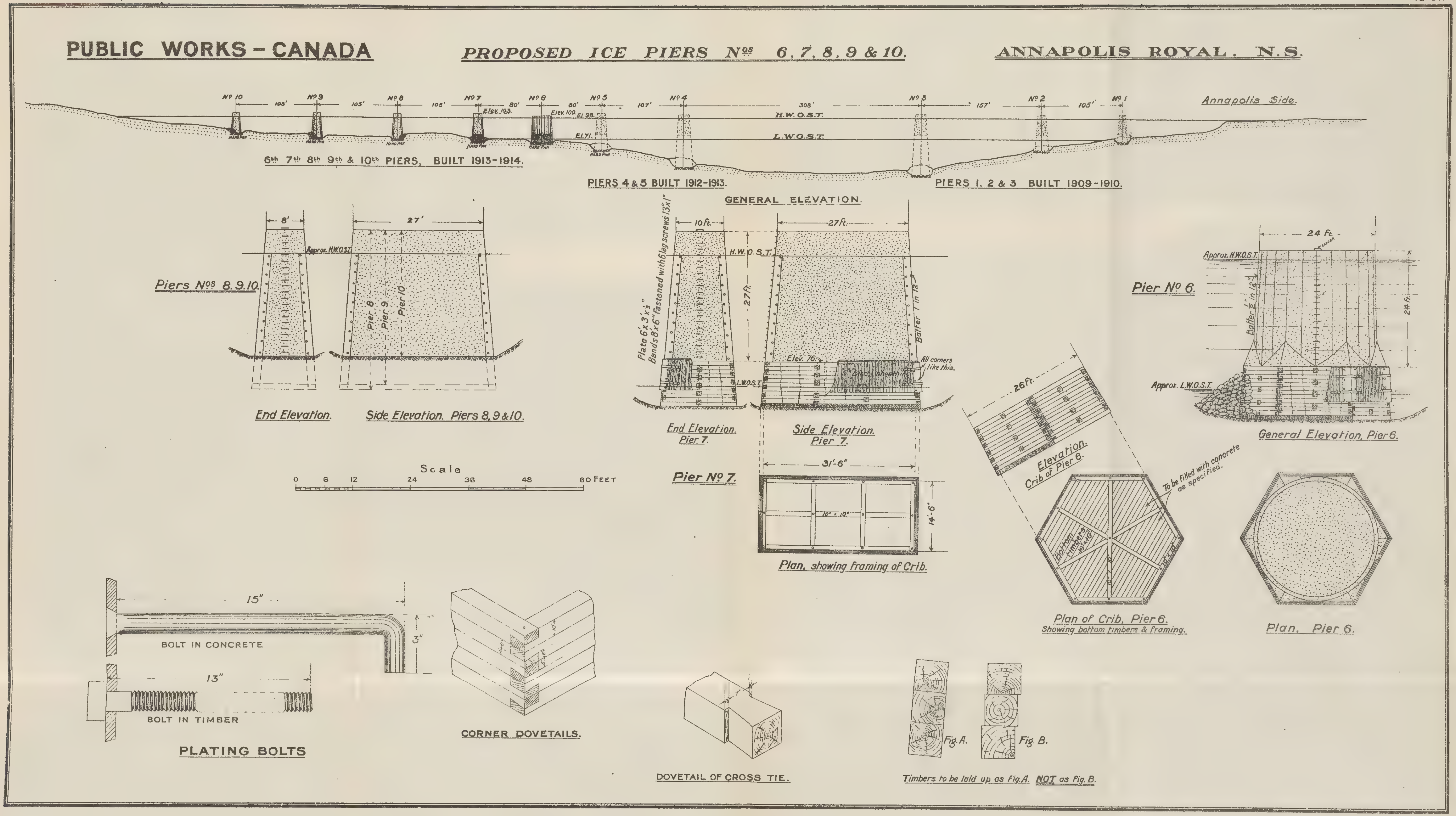
Local sticks are, however, too short for employment on the larger wharves and for these imported pitch pine or fir is almost entirely used. Such piles when creosoted have had to be renewed after 8 years' service, but a number of piles treated with two coats of hot tar appear to have lasted between 20 and 25 years.

Covering with copper or Muntz metal has been used. The metal when employed on the smaller posts is frequently stolen and in consequence concreting these piles between wind and water has been tried and seems to be satisfactory.

The larger pitch pine piles are sometimes given three coats of hot tar, covered with a sheathing of felt and then with Muntz metal. Two harbour stakes so treated are known to have been in use for over 21 years and are quite good; wharf piles have also been in use for over 20 years and still seem sound. The sheathing in such cases is carried into the mud and above high water for about 2 feet. Concreting large piles between wind and water has also been recently resorted to and reinforced concrete piles have been used for wharves.

The most reliable information obtainable here is from the Admiralty piers at Port Royal. In 1881 one pier was renewed with pitch pine piles 15 inches square by 53 feet, covered with 16 gauge copper to 1 foot below mud level. These piles, after 36 years' service, are still in fair condition. In 1904 some round creosoted spruce fir piles, 45 feet long, were driven. These piles after 13 years' service are in many cases eaten through by the teredo and are in a much worse condition than the older piles. Similar piles were driven in 1910; these are in better order than the 1904 piles, but this is probably the result of their shorter life. The creosoted piles are

FIG. 37.


PUBLIC WORKS - CANADA
PROPOSED ICE PIERS Nos 6, 7, 8, 9 & 10.
ANNAPOLIS ROYAL. N.S.
Annapolis Side.
H.W.O.S.T.
L.W.O.S.T.
6th 7th 8th 9th & 10th PIERS, BUILT 1913-1914.
PIERS 4 & 5 BUILT 1912-1913.
PIERS 1, 2 & 3 BUILT 1909-1910.
GENERAL ELEVATION.
Piers Nos 8, 9, 10.
End Elevation.
Side Elevation. Piers 8, 9 & 10.
End Elevation. Pier 7.
Side Elevation. Pier 7.
Pier No 7.
Plan, showing framing of Crib.
Pier No 6.
General Elevation, Pier 6.
Elevation. Crib of Pier 6.
Plan of Crib, Pier 6.
Showing bottom timbers & framing.
Plan, Pier 6.
To be filled with concrete as specified.
All corners like this.
Scale
0 6 12 24 36 48 60 FEET
BOLT IN CONCRETE
BOLT IN TIMBER
PLATING BOLTS
CORNER DOVETAILS.
DOVETAIL OF CROSS TIE.
Fig. A.
Fig. B.
Timbers to be laid up as Fig. A. NOT as Fig. B.

now being replaced by 45-feet piles of southern yellow pine, specified to be treated with 25 lbs. English Becton dead oil of coal tar to the cubic foot of wood. The piles are to be sheathed with 20 gauge copper for 9 feet above and 9 feet below water line. Another pier with pitch pine piles said to have been creosoted 18 lbs. to the cubic foot was built in 1903. These piles were 20 feet long, average diameter 9 inches, and were renewed in 1916 many being entirely eaten through. Two concrete piles in another pier have been quite satisfactory.

The most common form of decay is rotting between wind and water. Where the water is salt, barnacles and the teredo inflict great damage, and are the chief cause of decay.

NOTES ON REPORTS RECEIVED FROM THE CORRESPONDING MEMBERS.

Prepared by M. F. G. WILSON, a Member of the Special Committee.

TIMBER STRUCTURES.

As might be expected, in dealing with a material so variable as timber, except in a few main directions, it is not possible, from the reports which have been received from corresponding members engaged on sea works in different parts of the world, to draw conclusive or general rules as to the behaviour of timber under any given conditions. Anomalous and contradictory results, even in the same locality, and frequently in different parts of the same structure, are of constant occurrence.

Mr. Trench, the Engineer-in-Chief of the London and North-Western Railway, in his report on Holyhead Harbour, calls attention to this fact, and gives the following instances:—

Greenheart.—Two piles 12 feet apart, both in position for 20 years; one is eaten to a depth of 2 inches all round, and the other shows only slight traces of attack.

Clean Pitch Pine.—Two piles 12 feet apart, both in use 20 years; one eaten completely away, the other to about 9 inches by 9 inches.

Creosoted Pitch Pine.—Two piles 40 feet apart. One fixed 9 years eaten to about 9 inches diameter, and the other, fixed 10 years, shows no sign of attack.

Creosoted Baltic Fir.—Two piles 110 feet apart. Age of one over 23 years, attacked in a few small patches; the other, fixed 18 years, is irregularly eaten into pot holes 3 inches to 4 inches deep.

All the above piles were originally 14 inches square.

Again, Mr Walsh (Sydney Harbour) says:—"For some unknown reason an occasional turpentine pile will be attacked by teredo whilst others surrounding it remain untouched."

References to similar inconsistencies in the behaviour of timber appear constantly throughout the reports received from corresponding members. These are variously attributed to differing conditions in the growth of the timber as regards climate or soil, season and method of felling, and so on; also to the considerable variation in the destructive activities of the marine organisms in different parts of the world.

General conclusions.

There are, however, certain broad general conclusions which the reports would appear to justify, viz:—

(*a*) No timber of whatever description, or under any conditions, is

entirely immune from attack by marine borers, or insects, when exposed to their influence.

(*b*) Greenheart, as regards the power of resisting these attacks, is by far the best timber, and surpasses all others in this respect.

(*c*) Chemical preservatives, whether used as injections, or in the form of surface paints, merely act as deterrents to the worm action, thereby prolonging the life of the timber to a greater or less extent, but they do not provide immunity from attack.

(*d*) Sheathing with metal or concrete, if carefully done, appears to afford valuable protection, but there are many difficulties with regard to its practical use, which detract from its efficiency.

(*e*) Timber is subject to attack from marine borers anywhere between high water and sea-bed level.

(*f*) The zone of principal attack is from a little below low water to a little below high water levels, and it is worst in the neighbourhood of low water.

(*g*) Worm action does not generally extend below ground level, nor apparently under protective sheathing, if the latter is complete and in perfect condition.

(*h*) Exposed ends of timbers, especially near low water level, such as the lower ends of diagonal bracing, lower walings, etc., are specially liable to attack.

(*j*) A very vulnerable spot is at bolted joints between timbers, such as where bracings or walings are attached to the piles, especially if the timbers have been notched where they meet.

(*k*) The presence of sewage, or fresh water, in any appreciable quantity, has a marked effect in diminishing the ravages of marine worms.

(*l*) In tropical and sub-tropical waters the marine destructive organisms are much more active than in temperate waters.

(*m*) The principal agents of destruction mentioned in the reports received from corresponding members are teredo and limnoria, and these are found in all climates ; but the activity of the teredo would appear to be increased by the warmer waters in a greater degree than that of the limnoria. Reference is also made in some of the reports to destructive action by the chelura, sphæroma and pholas.

Durability of Timbers.

The varieties of timbers used, and the differences of climate or conditions to which they have been exposed, as referred to in the reports, are so numerous that it is impracticable to form a concise summary of the results, or to tabulate the timbers, in any reliable degree, according to their durability, so that only a few general conclusions are possible, except in regard to greenheart, which, as already stated, appears to be far superior to any other timber in its power of resistance to attack.

A remarkable instance of the durability of greenheart is given by Mr. Newell, the Engineer-in-Chief of the Mersey Docks and Harbour Board, in describing some dock gates at Liverpool, constructed of green- Greenheart.

heart, and erected in 1857. In 1896 they were taken down for alteration, and were found to be practically in as good a condition as when first erected; mortices and tenons being still perfect. The gates were re-erected after alteration, and in 1918 they were still in first-class condition, having then been in use 61 years. Liverpool, however, appears to be specially free from marine pests, for oak gates, 70 years old, are referred to as still sound. Pitch pine and Baltic timber were sound after 30 years.

At Portsmouth, greenheart fenders were found in good condition after many years exposure to marine action.

In warmer waters the life of timber is not so long, but at Auckland, N.Z., greenheart is referred to, which had been in use 25 years, though badly wormed at about half tide level, the extreme rise of spring tide is here 12 feet.

At Singapore, greenheart fenders were found to be generally sound and in good condition after 8 years, whereas the life of ballow[1] fenders under similar conditions would not have been more than about 5 years.

Mr. Messent, the Chief Engineer of the Bombay Port Trust, has forwarded a report by the late Mr. Squire, prepared in 1889, on repairs to dock gates built of Demerara greenheart. The length of time the gates had been in use is not stated, but they appear to have suffered considerable deterioration, particularly from pholas.

The report says that (in addition to other places), "The planking was freely attacked by pholas and teredo, especially on the harbour side. Between 73·00 and 76·00 on T.H.D. (apparently about 2 to 4 feet above low water) the pholas was abundant . . . but none of the holes probed were more than 1 inch deep." . . . "Fortunately neither the teredo nor the pholas appear to have penetrated to any depth into the main timber of the gates, for when dressing off the sill-pieces the solid heartwood was found without a trace of either . . . not more than 1½ inch from the outer surface."

Pine and fir timber.

In home waters the principal timbers referred to are the various European and American pines and firs, which are used both in their natural state or preserved with creosote or by other means. Pitch pine would appear to be the timber most generally used on the whole. Except in special cases, where the water was brackish or impregnated with silt, the life of these timbers, even when creosoted, would not seem to exceed, say as a maximum, from 20 to 25 years. At Southampton a quay constructed of creosoted pitch pine was found after 20 years to be unsafe, and had to be entirely replaced. The opinion is more than once expressed that creosoted Baltic fir is superior to pitch pine in its power of resisting worm action, on account of its being capable of absorbing a larger quantity of creosote.

Mere hardness of timber does not increase its immunity from attack. Numerous instances are given of oak being quickly destroyed.

At Hartlepool, elm was rapidly destroyed. At Southampton, American elm and oak suffered severely. At Portsmouth, English and American

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[1] Ballow is considered to be one of the best of the timbers for sea work which can be obtained locally.

elm were found to have a life of only 7 to 10 years. Mr. Walsh states that at Sydney, ironbark, a very hard and close-grained local timber, was destroyed there as quickly as pine.

Australian and Tasmanian timbers, such as jarrah, karri and blue gum, have been used with good results in home waters. At Dover, Tasmanian blue gum piles, extensively used in temporary stagings, were found after 8 years to be very little affected, except on the outer surface, which was lightly attacked by limnoria. The outer skin where the worm action had taken place was sawn off and the piles were re-used in permanent work. At Southampton, jarrah and blue gum were found to be only slightly attacked after 6 years. At Yarmouth, jarrah has been in use upwards of 25 years with satisfactory results, although the teredo is comparatively active there, considering it is a home port. Australian and Tasmanian timbers.

Owing to the great similarity both in colour and structure of jarrah and karri timber, much difficulty has from time to time been experienced in pronouncing an opinion concerning specimens of these woods. It has been shown, however, that on applying to a freshly-cut surface of the timber a drop of caustic soda solution of a specific gravity of 1·2°, the stain produced on the jarrah is much darker than on the karri. Another simple means of distinguishing between the two woods is to burn a thin splinter of wood freshly cut, when the ash of the jarrah is very firm and dark, almost black, while that of the karri is woolly and nearly white.

Mr. Kirkpatrick (Port of London) refers to a jetty at Purfleet constructed in 1899 entirely of karri. From half-tide level to low water the timber is perfectly sound. Upwards to high water the surface is softened and decayed to a depth of about $\frac{1}{4}$ inch. Above high water the timber appeared as new, except for longitudinal cracks in the struts.

Tasmanian blue gum, karri and jarrah were used in connection with pier works at Fleetwood, carried out in 1907 and 1913. Comparing these timbers with Oregon pine, Mr. Rattray, the Engineer to the Docks, says: "The latter (Oregon pine) has been much affected by the sea-organisms, the karri and jarrah slightly so, and the blue gum only to a small extent, if at all."

In tropical and other warm waters, however, these timbers do not, in some cases, appear to be very much superior to ordinary creosoted pine or fir. At Singapore it was stated that Tasmanian blue gum stage piles were eaten through in 18 months. At Colombo, jarrah piles were destroyed in 2 years. At Table Bay a karri pile 18 inches by 18 inches was said to have been almost eaten away in 11 months. Tropical waters.

At Bombay it is stated by Mr. Messent that an examination of two jarrah piles, which had been in position $2\frac{1}{4}$ years, showed that at about 4 feet above low-water spring tide the sapwood was readily attacked by teredo and pholas. A karri pile showed no signs of teredo, but had been slightly attacked by pholas.

In such waters the reports show that most timbers have a life of only a few years. One of the most satisfactory timbers appears to be turpentine, obtained from New South Wales. Mr. Hamer, the Engineer to the Auckland Harbour Board, N.Z., refers to its use at Auckland as Turpentine timber.

satisfactory, and speaks of it as being only slightly attacked after 9 years. Mr. Walsh (Sydney Harbour) has used turpentine piles to a large extent, and, when driven with the bark on, has found them satisfactory. He states that of many such piles, drawn after being from 10 to 40 years in the water, only about 10 per cent. were found unfit for further use, and only about half of this number had been destroyed by teredo. On the other hand, at Madras, turpentine piles were practically destroyed in 12 years.

Other timbers.

Totara, a New Zealand timber, also appears to possess good resisting power. Mr. Hamer places its life at 15 years. Mr. Marchbanks (Wellington) states that this timber was largely used for piles at Wellington Harbour, and resisted teredo very well.

Mr. Ellis, in his report upon Hong Kong, where he has been engaged on pier and wharf works, alludes to wharves 25 to 30 years old, constructed of aranga timber, obtained from the Philippine Islands, which was still in sound condition below water level, and he describes the timber as being "the only timber known in the Far East which almost entirely resists the attacks of teredo." No particulars, however, are given as to this timber, with regard to sizes, procurability, etc.

Effect of Fresh Water or Sewage on the Life of Timber.

There would appear from the reports to be no doubt that the presence of fresh water or sewage contamination has a very deterrent effect upon the activities of marine pests, and many references are made to this question. It would also seem that the teredo is more quickly affected by the presence of fresh water than the limnoria.

Cork Harbour.

At Cork Harbour, between Cork and Passage, where the sea water is largely diluted with river water and sewage matter, soft wood piles 60 years old were quite sound. Between Passage and Queenstown, the limnoria was shown to be active on soft woods. Between Queenstown and the sea, teredo and limnoria were both found to be active. Mr. Price, the Engineer to the Cork Commissioners, in his report, gives the following table, showing the proportion of fresh to salt water at the different places just referred to:—

At Cork	Fresh water	76	per cent.
,, Passage	,,	5	,,
,, Queenstown	,,	4	,,
,, Harbour Entrance . . .	,,	$2\frac{1}{4}$	,,

Leith.

Mr. Roberts, the Port Engineer, referring to Leith Harbour, states that a pitch pine pier, erected in 1848, apparently lasted well till 1893, when sewage was diverted from the harbour, after which the deterioration of timber became more rapid.

Grimsby.

At Grimsby, about 20 per cent. of the water is stated to be fresh, and although limnoria appears to be very active, no teredo is found.

Tyne.

The joint report on the Tyne by Mr. J. M. Moncrieff and Mr. R. F. Hindmarsh contains some interesting particulars in this connection. A jetty, constructed in 1855-9 of creosoted Baltic fir, in water impregnated with sewage and chemical refuse, showed no signs of decay, whereas near

by, in a dock quay constructed in 1864–5 of the same material, but where the sea water was replenished each tide and no fresh water or sewage matter was present, the timber was badly worm-eaten. Generally speaking, the nearer the structures are to the mouth of the river and the presence of pure sea water, the greater becomes the worm action. Above the Northumberland Dock no worm is found, this being attributed to the pollution of the river.

At Garston Harbour, 22 miles above the Mersey bar, where the sea water is affected both by land water and sewage and trade effluents, Mr. Trench states there is practically no deterioration by marine organisms. Garston.

Sir John Griffith found at Dublin that in the upper harbour, where the water is polluted with sewage, the timber was uninjured, whilst in the lower harbour, where the water was uncontaminated, the destructive action was very rapid until the advent of oil vessels, when the leakage of oil into the harbour put an end to the activities of the worm. Dublin.

In the structures described by Mr. Kirkpatrick, the Engineer-in-Chief to the Port of London Authority, there does not appear to have been much serious damage attributable to marine organisms, due, no doubt, to the considerable proportion of fresh water in the Thames estuary; this being as much as 50 per cent. at low water and 25 per cent. at high water at Northfleet. Mr. Kirkpatrick further states that no teredo is found above Gravesend. Port of London.

Mr. Gilbert, dealing with Belfast, states that over a period of 40 years there are practically no traces of marine organisms, the water being generally dirty, containing mud and quantities of sewage and vegetable matter. But with regard to newer quays, which are developing seawards, he refers to a reduction in the life of timber, and states that, in consequence, concrete will probably be substituted for that material. Belfast.

Two interesting examples of the absence of teredo in specific spots, whilst active in neighbouring waters, come from New Zealand. In his report on Dunedin Harbour, Mr. Mason refers to the absence of teredo, though it is found in adjacent harbours. He accounts for its absence as being due to the discharge of sewage into the estuary, and states that timber generally has stood well, and ironbark was in good preservation after 40 years. At Port Lyttelton, ironbark was found absolutely sound after 40 years in the water, the reason not being apparent, but the presence of volcanic sedimentary matter in the water was suggested. On the other hand, Mr. Marchbanks, at Wellington Harbour, found that ironbark, if not sheathed, was soon attacked by teredo. In an appendix to Mr. Hamer's report on Auckland Harbour it is stated that ironbark is at once attacked and destroyed most rapidly. Mr. Walsh, reporting on Sydney Harbour, says, as already mentioned in these notes, that ironbark is destroyed as rapidly as pine. New Zealand.

Mr. Crosthwaite, in his report on Lowestoft Harbour, states that on the north beach, where there is a considerable accumulation of shingle, pitch pine groynes were but little attacked, as compared with those on the south beach, where shingle was absent, and he suggests that the immunity of the groynes on the north beach may be due to the constant battering of the timber by the shingle, preventing the borers from attaching them- Lowestoft.

selves. In this connection the writer may mention that at Spurn Point, where there is a large travel of shingle, groynes which have been in existence many years show comparatively few signs of deterioration.

Thames Haven.

The experience at Thames Haven, near the mouth of the Thames, reported by Mr. Robertson, Engineer to the London, Tilbury and Southend section of the Midland Railway, is also interesting. Three timber piers are described, two being constructed of creosoted Dantzic fir and the third of uncreosoted pitch pine. They were built at varying dates from 1854 to 1889, and have all suffered severely from worm action, particularly that constructed of uncreosoted pitch pine, which was also the last to be built. This experience is in direct contrast to that gained in respect of similar piers, constructed higher up the river, and described in connection with the Port of London, where the proportion of fresh water is considerable. Mr. Robertson mentions as an interesting feature that the action of the worm ceases about 2 feet above ordnance datum (the spring range being 18 feet 6 inches). The water is below that level from 5 to 6 hours during each tide, and Mr. Robertson infers that the activity of the worm is affected by a long exposure to the air. He further states that the timber in the piles, above the reach of the worm and below the river bed, was still quite sound after a life of 60 years.

Portsmouth.

Sir T. Sims, formerly Director of Works of the Navy, in dealing with Portsmouth Harbour, points out that the destructive action of the borers is most marked in crevices and angles of structures protected from the sun and the drying effects of the air during low tide periods.

Protection of Timber.

The methods adopted to aid in the artificial preservation of timber as described in the reports, consist chiefly in the use of (1) external paints, (2) internal impregnations, and (3) metal or other sheathing.

Under head (1) the commonest application is that of tar, or tar and pitch, to which frequent references are made. At Table Bay, Mr. Nicholson, the Port Engineer, experimented with various preservatives, which he describes in his report, and he ultimately came to the general conclusion that soft wood "coated with some preparation of tar or similar substance which will penetrate well into the wood" would best resist attack.

Charring.

A system of charring, called the "Carbo-teredo" process, is referred to in several of the reports. It apparently consists in coating the surface of the timber with crude petroleum, and then charring the wood by means of a blow lamp to a depth of $\frac{1}{4}$ to $\frac{1}{2}$ inch. In describing tests with this process at Sydney, extending over about 2 years, Mr. Walsh says that while not rendering the timber immune, charring prolongs its life very considerably.

Mr. Thompson, in describing its use at Perth, Western Australia, says that the process produces a fine, even char. He further states that in his experience "charring and boiling in tar confers a large measure of immunity against teredo and limnoria attacks."

Sir T. Sims gives some particulars of charring experiments at Ports-

mouth which extended only over 12 months, but seem to show that the charring was of some benefit.

A process termed "Powellizing" is also referred to in some of the reports, though its nature is not described.

Better results seem to have been obtained under head (2) by impregnating the timber with creosote, and this process is frequently referred to in the reports, though it is by no means entirely efficacious. At Southampton it was found that the surface only was fairly immune, the heart of the timber being destroyed. The same remarks apply to Portsmouth, where it is stated that in many cases the creosote failed to penetrate the wood to a depth of more than $\frac{1}{2}$ to $\frac{3}{4}$ inch. Creosoting.

The New Fish Dock Pier at Grimsby was constructed in 1906 under Mr. Cartwright, partly of creosoted red fir and partly of uncreosoted pitch pine. The creosoted timber is reported as being quite sound, but the pitch pine has been eaten away by limnoria to the depth of 1 inch.

At Dublin, Sir John Griffith found that creosoting by the Bethel process was in his opinion mainly superficial. He considers high temperature creosoting to be much more effective, on account of the large quantity of creosote absorbed, but the process is somewhat costly. At Yarmouth, it was found that, when properly creosoted, Memel offered considerable resistance to teredo, having a life of about 25 years.

Mr. Alston, Engineer to the Clyde Navigation Trustees, referring to work on the Clyde, says that impregnation with 8 lbs. of creosote per cubic foot is an excellent preservative of timber, piles driven 58 years ago being still in good condition. In this case, however, the preservation seems to have been chiefly as regards ordinary decay, as the water in Glasgow Harbour is contaminated and much diluted, and is said to be free from sea-organisms.

Creosoted timber is not often referred to as being used in tropical waters, but at Colombo creosoted Baltic fir, impregnated with 14 lbs. of creosote per cubic foot of timber, had to be replaced in two years.

The chief difficulty in connection with this process is to get the creosote to penetrate sufficiently into the timber. For this reason the process is unsuitable for hard woods.

The third method referred to, viz., metal sheathing, appears to have been effective, if thoroughly well done. The great difficulty lies in properly covering the joints between the timbers in braced structures, and it is also a very expensive process. The usual method is to cover the timber in the first instance with tarred felt, over which the metal sheathing is secured. Sheathing.

At Fleetwood, it is stated that lead, secured by copper nails, was used for the sheathing in connection with the Wyre Lighthouse, erected in 1872, and this has prevented all damage from sea-organisms.

At Brisbane, 22 oz. Muntz metal, secured by Muntz metal nails, was laid over brown paper or felt payed over with Stockholm tar, and Mr. Cullen states that ironbark piles protected in this way "will last indefinitely, or at least up to 40 to 50 years." Before sheathing, a solution of 1 lb. arsenic, 2 lbs. carbonate of soda, 4 gallons of water, followed, when dry, by a solution of sulphate of copper, was liberally applied.

At Wellington, N.Z., Muntz metal sheathing to piles, extending from 12 inches below ground level to 6 inches above high-water spring tides, has always been used, Muntz metal bolts being also used for securing the bracing and wales. Some of these, which have been in use since 1862, are reported to be still in comparatively good order. Mr. Marchbanks, however, states that since 1890–95 it has been found that the metal supplied was not so satisfactory as previously, and comparative analyses are given. Latterly a composition consisting of 99 per cent. copper and 1 per cent. tin has been used, and appears to have given satisfaction.

At Sydney, Muntz and other yellow metals have been used, but the quality of the metal varied considerably, so much so that in 1903 Mr. Walsh discarded its use entirely, having found that in some cases only 2 or 3 years' protection was afforded.

Reporting on Perth, Mr. Thompson says that Muntz metal sheathing is effective if the alloy is homogeneous. If there is segregation the zinc rapidly disappears, owing to electrolytic action.

Concrete casing.

Encasing piles with concrete is referred to in several reports. At Wellington, piles were surrounded by a light steel box, bolted together in halves, after the piles were driven, leaving a space of from 4 inches to 6 inches between the box and the timber. This space was then filled in with 3 – 1 concrete poured through a tube, and proved satisfactory. The casing extended from 12 inches below ground level to a little above low water.

At Belawan, piles before being driven were encased, according to Mr. Ellis, with $1\frac{1}{2}$ inch Portland cement plaster laid on expanded metal, and reaching from below mud level to just above low water. It was found that the teredo attack ceased about 1 or 2 inches below the upper edge of the cover.

At Perth, cylinders with socket joints were formed of 1 part cement to 3 parts sand. The cylinders were about 4 feet long, 2 feet in internal diameter and $1\frac{1}{8}$ inch in thickness, and were reinforced with wire netting. When ready for use they were threaded over the pile after it was driven, the space between the pile and the cylinder being filled in with sand. Hitherto no deterioration has been visible, but the length of time during which they had been in use is not stated.

A somewhat similar system has been used by Mr. Walsh at Sydney. In this case the space between the cylinder and the pile was filled in with concrete. It has been in use 5 years with no evidence of deterioration.

On the other hand, the plan of encasing piles with concrete at Portsmouth is stated to have been "not quite a success."

Scupper nailing.

The system of scupper nailing, i.e., driving flat-headed iron nails into the timber, nearly touching each other, so that the space between them may rust over and form practically a continuous rust coating, is mentioned in connection with Southampton, Yarmouth and Dublin.

A beacon pile treated in this way at Portsmouth, and believed to have been in use about 25 years, is also described. The pile is of Memel, driven into the mud about low-water level. It was scupper-nailed for a height of 11 feet 6 inches, and is apparently quite sound.

REINFORCED CONCRETE.

Structures of reinforced concrete are referred to in a considerable number of the reports. On the whole they are satisfactory, though many instances of deterioration are mentioned.

Most of the remarks are of a more or less general character, though some cases are dealt with in considerable detail. It should further be noted that the general experience related does not, as a rule, extend over a period exceeding 12 to 15 years, and in some cases much less than that.

Nature of defects.

The defects which have been noticed and reported upon may be said to be almost entirely due to the corrosion of the steel reinforcements, resulting from the penetration of moisture through the concrete covering until it reaches the steel.

Access of moisture to the steel is attributed to various causes, the principal of which are :—

(*a*) Want of sufficient concrete over the steel reinforcements ;
(*b*) Porosity of the concrete itself ;
(*c*) Cracks which, from a variety of causes, may have developed in the concrete.

In several cases want of cover is stated to be due to accidental disturbance, or careless misplacing of the reinforcing rods or stirrups resulting in the metal-work being found too near the surface of the concrete. In other cases the vertical reinforcement, when in the form of links, is described as having dropped out of place, thus causing voids in the concrete, which admitted water to the reinforcement.

Level at which corrosion occurs.

The level at which corrosion chiefly occurs is not often specifically referred to in the reports, but where this is the case it is almost invariably stated to have taken place from about the level of high-water neap tides upwards.

Mr. Wentworth-Sheilds, in his report on Southampton, says :—

"It is interesting to note that this rusting action takes place only above high-water level ; below high-water neap tides, when the piles and bracing are kept constantly wetted, they are still quite unaffected, but above that level the piles, bracing, and underside of decking have suffered considerably."

Mr. Meik, in describing the pier at Purfleet, refers to cracks appearing in the surface of piles and bracing, which allowed moisture to reach the reinforcement, thus causing corrosion, and remarks that by far the greater number of cracks occurred about the level of high-water spring tides, the members at a lower level being generally in a very good state.

Mr. Marchbanks, Wellington, N.Z., refers to rust-marks and cracks as taking place well above high water.

Mr. Kirkpatrick, dealing with the Port of London, remarks that "the most striking feature of the examination was that no serious deterioration was found below high-water level."

Mr. Cullen, of Brisbane, gives numerous instances of the use of reinforced concrete for the construction of piers in various parts of Queensland. The examples cited are all of recent date, and in his experience it seems more necessary to protect concrete of this description from the action of moist air than from that of water. The work was found to be generally sound, except in the case of the employment of unsuitable materials and defective workmanship. Many of the cracks noticed were near the junction of the piles with the deep beams, and there were also cracks leading to the rusting of the reinforcing bars in some of the raking piles used instead of braces. Rust was caused in certain cases by the displacement of the stirrups, so as to leave but ¼ inch of cover.

Many references occur in the reports to cracks and corrosion taking place on the underside of the deck and deck-beams.

The general results of the reports appear to show that, as a rule, corrosive action is not found to take place below the level of, say, high-water neap tides. Mr. Sheilds attributes the immunity from corrosion below that level to the fact that the material is constantly wet.

Mr. Kirkpatrick says: "It is known that iron immersed in water from which the air is excluded, does not rust, and also that during the drying of the wet metal corrosion is very rapid. It is probable that to these two properties the different rates of deterioration of reinforced concrete above and below high-water level is due. Above high water, where the concrete cover is thin, moisture will find its way in to the steel in wet weather, and drying out during the fine periods will produce corrosion and crack the concrete. Below high water, on the other hand, the moisture will not have time to dry out between the wettings, and thus the steel is protected from those conditions which lead to rapid corrosion."

Corrosion. It is stated that the first signs of corrosion appear as small spots of rust showing on the face of the concrete. This is specially referred to in the case of Southampton, Fleetwood and Wellington. Cracks then appear, following the line of the reinforcing rods, the corrosion extending in a similar manner. Mr. Meik (Purfleet) says: "Once a crack is started, water or moisture gains access to the steel reinforcing bars, causing them to corrode, forcing the concrete away from the bars, and so permitting more water to get at the steel, thus accentuating the evil." Mr. Kirkpatrick states that the bursting force of the corroding steel has been measured, and found to reach as much as 4,700 lbs. per square inch. He refers to very serious corrosion which took place in connection with a jetty at Gravesend, many of the beams having become cracked throughout the whole of their lengths, exposing the bars. In some cases the whole side of the beam became detached. A detailed description of the damage done is given.

Mr. Sheilds (Southampton) points out that "the (corrosive) action is most marked in those parts of the structures where heavy rolling loads have to be supported." Mr. Meik, referring to the cracking of the inclined struts in the pier at Purfleet, says: "There is little doubt but that these cracks owe their origin to the racking strains brought on the

pier members when vessels come up against the pier in the process of being berthed alongside." Mr. Kirkpatrick, dealing with piers at Gravesend and Swanscombe, says that in each case greater deterioration has taken place in the approach than in the pier itself, which is probably due to the extra traffic over these portions. It is not suggested that the deterioration is caused by the traffic, but that deterioration having begun, it is accentuated by the strains produced by the traffic.

The only really satisfactory remedy for work injured by corrosion appears to be the entire removal of all the disturbed concrete, after which the corroded rods must be thoroughly cleaned, and the concrete replaced with rich material. Remedy for damaged work.

Mr. Kirkpatrick makes the following suggestions with a view to producing satisfactory work for reinforced concrete structures exposed to sea action:— Preventatives.

Structures should be designed with the smallest number of members practicable.

The greatest care should be taken in respect to workmanship.

No reinforcing bars in any important beam or column should have less than $1\frac{1}{2}$ inch of cover.

The use of flat stirrups should be avoided.

Iron bolts or plates for external attachment should not be embedded in the concrete.

Frequent references occur in the reports to the necessity of careful mixing, placing, and ramming the concrete, so as to render it as solid and non-porous as possible. Concrete.

Although the importance of rendering the concrete impervious to water is fully recognised in the reports, the question of the aggregate to be used in its composition has not been so fully dealt with as might be expected. Mr. Hamer (Auckland, N.Z.) describes a somewhat elaborate system of sifting or grading adopted by him, the principal points of which are:— Aggregates.

The largest stone must pass through 1 inch mesh.

From 45 per cent. to 60 per cent. by weight must be retained on $\frac{1}{5}$ inch mesh.

From 20 per cent. to 50 per cent. by weight must be retained on $\frac{1}{12}$ inch mesh.

The remainder, passing the $\frac{1}{12}$ inch mesh, is considered as sand. Total voids, after screening and ramming, must not exceed 25 per cent.

Mr. Wentworth-Sheilds (Southampton) considers that the whole of the aggregates should pass through a $\frac{3}{4}$ inch ring, but does not specify any further grading.

Mr. Marchbanks (Wellington, N.Z.) gives the following specification:—

River shingle screened to pass $\frac{3}{4}$ inch mesh, and retained on $\frac{1}{4}$ inch mesh.

Sand must pass through $\frac{1}{10}$ inch mesh, and be retained on $\frac{1}{76}$ inch mesh.

Proportions of cement and aggregate.

The proportions of cement to aggregate are given in a number of the reports, though several writers make no reference to this matter. The proportions stated are, however, not always strictly comparable, for in some cases they are given by weight of cement, sand, and broken stone or shingle before mixing, whilst in other cases the proportions are stated in measures of cement, sand, and stone after being mixed together.

The following table gives the proportions adopted by some of the engineers who have furnished reports :—

Mr. Hamer gives for piles and all work below high water	1 cement,	3½ shingle and sand.		
For girders and bearers above high water	1 ,,	4 ,,		
Mr. Wentworth-Sheilds gives, as a general description	1 ,,	4 aggregate.		
Mr. Meik gives for piles . . .	1 ,,	4 ,,		
For columns, bracing, and decking above high water	1 ,,	5 ,,		
Mr. Marchbanks gives for piles . .	1 cement,	2 sand,	3 shingle.	
Decking and bearers . . .	1 ,,	2 ,,	4 ,,	
Subsequently altered to . . .	1 ,,	2 ,,	3 ,,	
Mr. Kirkpatrick gives for piles . .	1 ,,	1½ ,,	3 ,,	
Decking and bearers . . .	1 ,,	2 ,,	4 ,,	

Generally speaking, it may be said that the proportions given in the reports vary from 1 of cement to 3 of aggregates for piles and work below high water, to 1 of cement to 4 of aggregates for beams, decking, etc., above high water.

Concrete cover to reinforcement.

The amount of cover, or thickness of concrete surrounding the steel reinforcement, is a matter of great importance, and is frequently referred to in the reports, the thickness being usually stated. Many cases of corrosion of the reinforcing rods, resulting in the distintegration of the concrete, are attributed to the want of sufficient cover to preserve the steel.

Mr. Hamer provides a cover of from 1¾ inches to 2 inches for all work in the tideway, and for girders and beams. For decking he allows ⅝ inch.

Mr. Wentworth-Sheilds considers, as a result of his experience, that "the thickness of concrete covering to marine work should be ample, say 2½ inches, and the material itself should be proportioned so as to be as non-porous as possible."

Mr. Kirkpatrick considers "that the amount of cover required in external reinforced concrete structures should be either sufficient to exclude all water and air from the steel, or sufficient to prevent the moisture drying out in the longest dry periods to which the structure will be subjected," and he finally concludes that for important members the cover should not be less than 1½ inch.

At Cork Harbour, Mr. Price allows 1 inch cover for piles, 1½ inch for water work.

Mr. Cullen (Brisbane) was led to consider that the thickness of 1½ inch originally allowed should be increased to 2 inches.

In several other cases $1\frac{1}{2}$ inch is given as the thickness of cover. It appears, therefore, that $1\frac{1}{2}$ inch may be taken as the minimum thickness recommended for piles, beams and similar work; a less cover being admissable in the case of the reinforcement for decking.

Water-proofing concrete.

The obvious benefit, if not the absolute necessity, of rendering the concrete surrounding the reinforcing bars impervious to water, has raised the question in several reports of applying a coating of some waterproof material to the surface of the concrete. No comparative experiments on any large scale appear to have been made, and such coating as has in some cases been applied, has not been in use for a sufficiently long period to enable a definite conclusion to be drawn as to its efficacy.

Use of tar.

Tar appears to be the principal material used, though other materials, such as ironite, siderosthen, etc., are referred to.

Mr. Sheilds mentions one of the quays at Southampton as having been coated with gas tar about the year 1910, in order to prevent water passing through the pores of the concrete. He considers the treatment lessened deterioration, though it did not altogether stop it, "probably because it was applied too late."

Mr. Rattray states that at Fleetwood, in order to remedy (corrosion) defects, all reinforced concrete work from and including the underside of the deck and deck beams, down as far as the water would permit, was given one coat of 8 parts tar to 1 part naphtha. This gave a good skin and dried in about $1\frac{1}{2}$ hour. The work was in progress at the time of his report.

Mr. Kirkpatrick considers that waterproofing should be of great assistance and, in corroboration of this opinion, instances an oil wharf at Thames Haven, which is constantly saturated with oil, and is very free from corrosion.

Mr. Cullen mentions the use at Cairns of a coat of cement wash.

Mr. Somers Ellis, referring to the deck of a reinforced concrete wharf at Shanghai, says: "The annual application of tar to this surface, which is marked by transverse contraction-cracks at regular intervals, appears not only to exclude rain water from the concrete, but to preserve the surface from wear, by forming a tough, non-friable skin." He further states that tar does not adhere well to new concrete; the structure should therefore be exposed to the weather for several months before the tar is applied.

Mr. Cullen also refers to the advantage of tarring the concrete above high-water level.

On the other hand, Mr. Hamer (Auckland, N.Z.) does not consider waterproofing to be necessary. He coated some concrete piles with various paints but found that none of them were lasting, and that in 12 to 15 months they had disappeared.

Concrete generally.

It is to be noticed that in no case are the defects in reinforced concrete work attributed to the concrete itself. Where specifically referred to, the concrete is invariably described as having been found to be sound and in good condition when cut into, which is extremely satisfactory.

ORDINARY CONCRETE.

It may be said that, with a few exceptions, the references to concrete generally throughout the reports are satisfactory. In a few cases, however, deterioration is stated to have taken place, and these will now be shortly described.

Deterioration of concrete at Scarborough.

Mr. Smith, Borough Engineer of Scarborough, states that he found the concrete-in-mass apron in front of the Royal Albert drive to be of the poorest description, such as could easily be broken in the hand; that it presented more the appearance of lime concrete than good cement concrete. He goes on to say that after finding concrete in other parts of the works also unsatisfactory, he decided to have the matter thoroughly investigated by Mr. Butler, and forwards a copy of Mr. Butler's report.

Mr. Butler's report.

The latter goes carefully into the question, and his remarks are accompanied by analyses showing that the cement of the damaged concrete contained an excess of magnesia and sulphuric anhydride. This Mr. Butler attributed, in some degree at any rate, and so far as it affected the concrete of the wall, to the percolation through the concrete, of land water highly charged with calcium and magnesium salts, chiefly in the form of sulphates; but he considered it to be an open question whether it would account for the injury to the concrete in the apron, which is almost always submerged. In this case he believed the presence of the salts to be more likely due to the concrete not being sufficiently impervious, so as to prevent the constant infiltration of sea-water.

Necessity for impervious concrete.

In this connection Mr. Butler says: "It would appear that the chief condition necessary for successful sea work with cement concrete, either above or below low water, is that it should be practically impervious, especially when exposed to the action of sea-water before it has become completely set, since the precipitation and deposition of magnesia, etc., in the interstices of the mass, hinders the setting process, and, in some cases, prevents it altogether."

Mr. Smith also points out that concrete in the form of blocks and set above water did not appear in any way affected, it being only concrete-in-mass put in between high and low water which showed these symptoms.

Southampton.

At Southampton, in the course of some alterations to the Trafalgar Graving Dock in 1912–14, i.e., about 12 years after it had been constructed, Mr. Wentworth-Sheilds says: "It was found that although the sea-water had soaked constantly through some rough places in the concrete and had softened the cement a little, the action was nowhere serious, and there had been no signs of the concrete swelling and bursting, as has been experienced in some other ports."

Hartlepool.

Mr. Howkins refers to a failure of the concrete in the old breakwater at Hartlepool, where an excess of magnesia and sulphuric acid was discovered. The deterioration was attributed to the action of a spring of gypsiferous water below the foundation of the affected portion of the work.

Concrete injured by frost.

Mr. Dodwell (Halifax, N.S.) describes the damage done to the face of some concrete-in-mass piers which he attributes to the action of frost. He states that during the high water period, water penetrates, no matter

how slightly, the surface of the concrete. When the tide is down the water in the concrete freezes and expands, and upon thawing again with the rising tide, the surface film of concrete falls off in powder. This action continuing through the winter gradually disintegrates the face. In about 7 years the maximum depth of the damage was about 15 inches, the average depth being less than 6 inches. The disintegrating action is gradually becoming slower; this, Mr. Dodwell considers, is due to the formation of a film of slime on the surface of the concrete which to some extent protects it. Mr. Dodwell is further of opinion that had it been possible to make the concrete absolutely impervious it would have suffered very little from the action of frost.

Wellington.

Mr. Marchbanks (Wellington, N.Z.) describing the deposition of concrete-in-mass through water, says: "In depositing concrete in this manner there is always a considerable amount of 'laitance' formed, a portion of which becomes mixed with the concrete and weakens it. There has not, however, up to the present time been a failure of any of the walls in Wellington Harbour due to this cause, although in several places local defects have been observed."

Tyne.

Messrs. Moncrieff and Hindmarsh, in their report on the Tyne, dealing with No. 4 Dock, Ballring Docks, North Shields, constructed in 1889, refer to the concrete sill as being very soft and loose, and as having to be entirely renewed in 1916. Copper slag appeared to have been used as plums in the concrete, but it is not said whether this was considered as being in any way the cause of its disintregation. In No. 2 Dock, 40 years old, the concrete of the sill and apron was apparently of a poor quality, being cracked in several places and very loose.

Referring to the North and South Piers at Tynemouth, they say lias lime, Portland cement and Roman cement have all been used in the construction of these piers. In certain places the lias lime had become decomposed and had expanded, thus causing trouble. In some cases the Portland cement concrete apron blocks have also become decomposed, but in no case has any decomposition taken place in the Roman cement.

General.

Generally speaking, it will be noticed that the importance of a concrete being impervious to water is frequently referred to.

Mr. D. A. Stevenson maintains, as the result of wide experience in the use of concrete round the coast of Scotland, that sea water has absolutely no effect on this material, if it is properly made from good and suitable ingredients. He states that no deterioration of any kind need be feared so long as the following precautions are observed:—

1. Cement of a low tensile strain should be selected.
2. Plenty of water should be used in mixing.
3. The proportions adopted must give an ample amount of cement to the other ingredients, otherwise the concrete is liable to be permeable and easily disintregrated.
4. Stones and sand used must be free from clay.

The pholas which bores into stone does not attack concrete.

The reports also point to the need of special care in connection with the deposit of concrete-in-mass in the tideway.

IRON AND STEEL.

General.

References to the use of iron and steel structures are frequent throughout the reports. Amongst the earlier structures described, cast-iron was largely employed for piles and columns, and to some extent for bracing struts, wrought-iron being used for ties. Cast-iron has in later years been in many cases superseded by wrought-iron, the piles and columns being formed of solid rounds, H. sections, and special built up sections, the bracing being usually of round bars with H. section struts where required. More recently, wrought-iron appears in its turn to have been, to a considerable extent, superseded by mild steel, some of the piers and wharves described being almost entirely constructed of that material. In these cases the piles, columns, and deck girders are of steel, the bracing frequently remaining of wrought-iron.

The reports do not afford such direct comparison between the behaviour of wrought-iron and steel as might have been expected. Corrosion is reported in the case of both metals, but on the whole it appears more marked in the case of steel than in that of wrought-iron. In most instances cast-iron seems to have been upon the whole quite satisfactory, except for a slight softening of the surface, which is several times referred to in the reports. Particulars as to quality or composition of the metal used are very seldom given.

References to iron and steel structures in home waters are less frequent than to those in colonial and tropical ports, so that a general comparison is not possible with regard to the effect of differences in climate and temperature upon those metals. Instances are given, however, in the case of tropical waters, of marked deterioration taking place at a considerable distance below low water, though, generally speaking, the worst effects are between high and low water, and more especially in the neighbourhood of low water.

Cast-Iron.

Dublin.

Dealing with the Port of Dublin, Sir John Griffith describes cast-iron piling, driven in the year 1847, say over 70 years ago, as having been converted into graphite, though its original form was still retained except where injured by abrasion. He attributes this non-disintegration to the fact that the piling was always kept wet by the tide, and he contrasts this with the behaviour of cast-iron cannon balls and bar shots, which when dredged up from the sea-bed were perfect in form, but when dried the surface burst off in layers, the whole being finally reduced to powder.

Port of London.

Mr. Kirkpatrick in his report on the Port of London, says that cast iron itself is almost unaffected by Thames Estuary water (i.e., about 75 per cent. sea-water at high tide and 50 per cent. at low tide), but where connections with wrought-iron occur below high water, deterioration takes place. This may affect either or both the metals, and is attributed as being probably due to electrolytic action. Cast-iron columns in the Royal Pier, Gravesend, are described as being in very

good condition after 73 years. Patches of incrustration, however, are found extending to about 18 inches above mud level, and under these patches the metal has become softened for a depth of about $\frac{1}{4}$ inch. Wrought-iron tie rods 2 inches in diameter were used. In the upper attachments of the rods to columns, at about 5 feet above high water, practically no deterioration was observable, but in the lower attachments corrosion was found to have taken place. In some cases the cast-iron lugs adjacent to the tie rod were softened, and the 2-inch rod was reduced to $1\frac{1}{2}$ inches diameter for a short distance above the eye. In Mucking Lighthouse, built in normal sea water in 1851, cast-iron columns, stayed with cast-iron bracing above low water, are used. The metal is generally hard and sound, but below high water there are, in places, soft patches, though only penetrating to a very slight depth. In some cases the heads of the wrought-iron studs securing the cast-iron braces are badly corroded

Mucking Light-house.

At Holyhead Fish Jetty, constructed in 1878, cast-iron columns above low water are in good preservation, being periodically cleaned and tarred. Below low water they are heavily encrusted, and the metal has perished for a depth of $\frac{1}{4}$ inch, resembling plumbago and being easily cut with a knife.

Holyhead.

At Wellington, N.Z., cast-iron piles 50 years old were found by Mr. Marchbanks in comparatively good order, though the outer skin was softened and could be cut with a knife.

Welling-ton.

At Auckland, N.Z., cast-iron in the plunger pumps of a caisson was found by Mr. Hamer to be quite soft after 25 years.

Auckland

At Madras, cast-iron screws for piles, which had been in use 50 years, were found to be unaffected. They had, however, been buried 10 to 20 feet below the sea bed.

Madras.

Wrought-Iron.

At the Royal Terrace Pier, Gravesend, there has been considerable erosion about high-water level in the case of the wrought-iron ties, forming part of the original structure built in 1844, but even in this case the parts above the reach of the tides and below half-tide level show practically no deterioration. Ties fixed in 1894 were found quite sound, the threads on the screw couplings being clean and sharp. Deterioration in the neighbourhood of the attachments to the cast-iron columns, attributed to electrolytic action, has already been referred to under cast-iron.

Graves-end.

Wrought-iron ladder rungs attached to the cast-iron columns of Mucking Lighthouse have become reduced 25 per cent. in sectional area close to the cast-iron near high-water level.

At Auckland, N.Z., the caisson for the Calliope Dock was built in 1888 of wrought-iron Crown or B.B. Staffordshire plates. After 25 years the metal, according to Mr. Hamer, was found to be generally in good condition. A few plates $\frac{3}{8}$ inch to $\frac{5}{8}$ inch in thickness on the inner or dock side, extending from about 2 feet above low-water level to 9 feet below, required renewal. These plates were pitted to the extent of about 40 per cent. of their thickness. The caisson of the Auckland Dry Dock

Auckland.

was built of similar material in 1878. After 8 years, several rows of plating near the bottom of the caisson required renewal. Some 25 years later, it was again docked for repairs, and several rows of plates had to be renewed and nearly all the riveting.

Wellington. At Wellington, N.Z., wrought-iron riveted girders were badly corroded in 22 years, and had to be replaced.

Madras. At Madras, wrought-iron screw piles, 8 inches in diameter, were found to be reduced by corrosion in 50 years to 7 inches, 6 inch piles being reduced to 5 inches, with occasional deep pit holes. Within the tidal range they had been worn down by the rubbing of boats and lighters as much as 2 to 3 inches. Below sand level no corrosion took place.

Aden. At Aden, screw piles 4 inches in diameter were found by Mr. Berridge, the Port Engineer, to be corroded from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch, with occasional $\frac{1}{2}$ inch pits, in 33 years. It is not certain whether the piles were of wrought-iron or steel, but presumably the former. On the other hand, the bracings, consisting of round rods and channel sections, were almost entirely gone.

Secondee. At Secondee, W. Africa, a wrought-iron jetty, erected in 1889, has shown generally but very slight corrosion or pitting.

Singapore. At Singapore, a wharf constructed of wrought-iron cylinders with struts and wales of the same material, was in good condition after 7 years. About the level of high-water neap tides slight rusting was noticeable, but very little elsewhere.

Colombo. At Colombo, a temporary staging of wrought-iron was in use about 9 years. Below water level this ironwork became coated with marine growth to a considerable thickness, except in isolated spots where the shellfish had become detached. In these last-named spots pits were formed in the surface of the iron to an appreciable depth, and were found to be filled with black powder. An old iron rail removed from the bottom of the harbour, where it had lain in all probability for many years, was found to be considerably corroded. The more fibrous parts of the metal were so reduced that the harder or crystalline portion projected above the surface of the rail head to the extent of $\frac{1}{8}$ inch to $\frac{1}{4}$ inch, thus showing the more rapid deterioration of the fibrous iron as compared with the crystalline portions.

Steel.

Leith. Mr. Roberts, referring to Leith Harbour, says that iron and steel dock gates, constructed at intervals from 1868 to 1911, and kept constantly painted, have not become appreciably deteriorated.

Southend. At Southend Pier, built 1891 and 1898, steel bracing was found hard and sound when the shellfish, with which the bracing was coated, were removed. The greatest corrosion of the tie rods, though in itself only slight, was noticed between 2 feet above and 2 feet below high water. On the other hand, the longitudinal and transverse girders above high water were badly oxidised.

Auckland. Mr. Hamer refers to a steel bridge at Auckland, N.Z., built in 1904, where some of the flat bar tension members, though kept carefully painted,

became pitted in circular patches. The bridge is just above water level. Though the metal was cleaned bright with a file, no paints or tars could arrest the rapid local corrosion on the bars, although adjacent members remained perfectly sound. The corrosion was attributed to some defect in the chemical composition of the steel.

An interesting case of corrosion is related by Mr. Somers Ellis, in connection with steel wharves erected at Kowloon, in Hong Kong Harbour, in 1907–9. The piles were H. section with bracings of steel rods and channels. Above low water the steelwork is scraped and painted annually, and is in good condition. Below low water the metal quickly became thickly coated with marine growth, but it was found after 2 years that pitting had commenced underneath the growth, which in 1913 had developed to a serious extent. The pitting reached to a distance of 20 feet below low water, being at its worst about 5 feet below that level. In 1915 some of the outer bays were taken down on account of alterations, and upon cleaning off the marine growth it was found that the deterioration had seriously weakened the various members. The pitting was oval in shape, up to $1\frac{1}{4}$ inch in length and $\frac{3}{8}$ inch deep. In many cases the metal was completely perforated. Similar pitting has been found in the wrought-iron piles used in connection with Blake Pier, likewise in Hong Kong Harbour. Hong Kong.

On the other hand, Mr. Anderson, also dealing with Hong Kong Harbour, considers that steel is eminently suitable for sea construction in that locality, and that below high-water level it is protected by the marine growth, and generally he does not agree with Mr. Ellis's conclusions.

At Madras, as set forth by the Hon. Sir Francis Spring, steel deck beams deteriorated very rapidly. A beam originally weighing 1,628 lbs. after 8 years weighed only 663 lbs. Beams near the shore end constantly splashed, corroded far more rapidly than those further out and not splashed so continuously. Madras.

A table is given of certain steel H. beams showing a loss of weight from corrosion in 8 years varying from 20 per cent. to 59 per cent.

At Sierra Leone, two jetties were constructed in 1907–8 of steel piles with wrought-iron bracing. The piles are but slightly rusted, but the tie rods from about 2 feet above low water to ground level were found to be considerably corroded and pitted. Sierra Leone.

At Karachi, an angle steel brace, removed from a jetty which had been constructed about 30 years, was found to have lost about 22 per cent. by weight through corrosion. Mr. Neilson points out that the corrosion was worst at about half-tide level. Karachi.

At Prai, in the Federated Malay States, a steel screw-pile pier, erected in 1911, has recently been taken down. A report from the Resident Engineer states that the steel of the piles, where embedded in the ground, was in almost perfect condition. From the ground to mean tide level the piles were thickly coated by a marine growth of oyster shells and barnacles, but on removing this coating "the surface of the steel was found to be considerably corroded by the holes being mostly filled pitting, up with a soft blackish powder, which could be easily scraped out. The Prai.

holes were numerous and very various in size and depth, running from the size of a pin's head to an area of $\frac{1}{2}$ to $\frac{3}{4}$ square inch, and up to about $\frac{3}{8}$ inch in depth. In some of the larger holes the small barnacles adhered firmly under a thin crust of the metal, it thus appeared as if the parasite had burrowed its way into the body of the steel." Above the coating of marine growth, up to high-water level, there was a considerable amount of ordinary corrosion, but above high-water level the steel was generally in very good condition.

Protection of Iron and Steel.

Coatings.

Scraping and painting, or coating with tar or a tar composition, from low water upwards, appears to be the most usual precaution taken. Mucking Lighthouse is described as being painted every 3 years above high water. Between high and low water it has a yearly coat of marine black composition. The ironwork of the Fish Jetty, Holyhead, is periodically cleaned and tarred above low water. Southend Pier is usually tarred every 3 or 4 years down to low water.

At Portsmouth bitumastic enamel is used for steelwork, cast-iron being protected with Angus Smith's composition, all apparently with good results. Sir T. Sims also refers to difficulties with regard to the corrosion of a steel gantry, supposed to be due to electrolytic action. Bitumastic coatings were not effectual, and in 1912 a covering of concrete $1\frac{3}{4}$ inch in thickness was substituted, which appears up to the present to have been satisfactory. He further points out that steel rusts more rapidly when alternately wet and dry, as also in confined spaces where condensation is set up, and he alludes to the necessity of having a clean surface, perfectly free from moisture, at the time of application of the preservative coating.

At Auckland, N.Z., some steel cylinder foundations, painted with red oxide paints, showed signs of rust in from 18 months to 2 years. They were cleaned down and washed with neat cement. This was repeated every 2 years with satisfactory results. For steel pontoons a single coat composed of red oxide with three parts of tar was found satisfactory.

Marine Growths.

The protection afforded by marine growth is frequently referred to. Mr. Berridge, at Aden, considers that marine growths, such as oysters, afford real protection to steel and iron. At Karachi a coating of $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, reaching downwards from about 18 inches below high water, has given satisfactory protection. Sir J. R. Nicholson, in his report on Singapore and Penang, considers such growth to be the best preventative against corrosion. He is of opinion that above half-tide level an application of hot tar and cement is suitable.

Mr. Alston (Clyde) observes that "a thick coating is formed upon the surface of all iron work by impurities in the water, and this seems to act as a preservative."

At Colombo, wrought-iron piles were found to be completely protected below low water by marine growth, except in spots where the shells had dropped off. Here, pits were formed completely filled with a black powder, as previously described. It was considered that in another 10 years the pitting would have affected the strength of the piles.

At Singapore, the Resident Engineer refers to the iron and steel work being covered with oysters and marine growth from about high-water neap tides downwards. On breaking this growth it came away with a hard black scale, which latter turned to a brownish-red colour on exposure to the air, and is described as consisting of sulphide of iron.

It will be remembered that Mr. Ellis, at Hong Kong, found sulphide of iron in the form of black powder in the pitting which became so serious at that port. It is probable that the black powder found in connection with the marine growth at Colombo and at Prai is of similar composition.

References to galvanising are very rare in the reports submitted, which is somewhat curious, as it is used to a considerable extent for the protection of iron and steel in sea-water. Galvanising.

In a report by the late Mr. Squire upon the examination of dock gates at Bombay, forwarded by Mr. Messent, it is stated that the whole of the galvanised wrought-iron work was found in good condition, the zinc being quite good. At Singapore, on the contrary, galvanised work was found in many cases not to be standing well. Boat steps, handrails and the lower portions of ladders, which had not been more than 2 years in the water, were badly rusted. Also the wrought-iron bands securing the fenders, when above the level of marine growth, were much corroded, but below this level, when the adhering shells were removed, the galvanising was found intact. Above cope level, handrails, stanchions and similar work, where beyond the reach of the ordinary splash of the waves, were in excellent condition.

At Hong Kong Mr. Ellis is now encasing his steel piles in concrete, and the same is being done in regard to the wrought-iron piles in the Blake Pier at that port, previously mentioned in these notes. Concrete Casing.

Sir Archibald Denny has contributed an interesting and valuable communication with regard to the use of preservatives for steel. Sir Archibald's remarks deal naturally with preservatives used in connection with shipping, but they are also of general interest and value. Preservatives.

The paints used are principally red lead and iron oxide, and provided they are well mixed with first class oils and driers, one is practically as good as the other.

Corrosion is found to be specially heavy in that portion of the vesse under the boilers, where it may be subjected to considerable heat.

A practice has arisen of coating the inside of the double bottoms of vessels with bitumastic paint applied hot, and this is found to be superior to the paints above referred to.

For the outside of the vessels above the load line, red lead or iron oxide paints are again used, though Sir Archibald appears to prefer the iron oxide. Below the load line anti-fouling composition must be provided as well as the preservative paint.

Sir Archibald is of opinion that the efficiency of anti-fouling compositions is entirely due to the amount of poison which is introduced into their composition. This is usually an arsenical compound, but sometimes a mercurial compound is used.

Use of Paint on Hot Plates.

Sir Archibald refers to the fact that steel plates when delivered at the works are covered with an oxide bloom. They are marked when hot with ordinary paint. When the oxide bloom scales off the plates are brushed with a steel brush before being painted with the anti-corrosive composition. It has been found that those portions of the plate which were marked when hot with paint, as above referred to, resist the weathering, and the oxide bloom is preserved. Sir Archibald argues from this that if possible it might be advantageous, in the case of steel structures which are to be permanently submerged, that the material should first be strongly heated before being painted, the heat being sufficiently great to make the paint smoke when applied.

GENERAL REPORT OF THE COMMITTEE EMBODYING THE RESULTS OF THEIR INVESTIGATIONS TO DATE.

THE preliminary proceedings which led to the formation of the Committee, appointed by the Institution of Civil Engineers, to investigate questions which affect the deterioration of structures exposed to sea action are described in the Introduction to this volume.

Appointment of Corresponding Members.

2. As there stated, one of the first steps in connection with the procedure to be adopted, after the appointment of the Main Committee, was to arrange for the co-operation of Corresponding Members, the latter being engineers in charge of some of the principal ports at home, in the Dominions and Colonies and in India.

3. After due consideration it was decided that the subject to be dealt with by the Main Committee could with advantage be divided into two heads, viz. :—

(i) The collection of information at present available, at different ports, as regards the effects of sea-water and sea-organisms on the respective classes of structural work which already exist at such ports. In this connection it appeared desirable that information should be procured, with respect to materials and works, which had satisfactorily withstood the action of sea-water and sea-organisms, and also to obtain particulars with reference to the destructive effects which had been produced in consequence of such action.

(ii) The organization and carrying out of *experiments* specially initiated for the purpose of this research. In this connection the Corresponding Member, or engineer at each port, was desired to refer to the materials which could be locally procured with which he proposed to experiment, in addition to those which would be prepared and forwarded to him from this country for that purpose.

Nature and Scope of the Investigations.

4. An intimation was also conveyed to the Corresponding Members, to the effect that one of the main purposes of the investigations was to ascertain what materials were most suitable at different ports, and would

be least liable to destructive effects from sea-water and sea-organisms, based on their experience in connection with the structures immediately under their charge.

5. With regard to the existing works, information was sought respecting the destructive effects of teredo, limnoria, or other sea-organisms, and the correspondents were also requested to give a brief description of the works, with conditions of exposure, character of materials, and other data bearing on the subject.

6. It was likewise intimated that information was desirable with respect to the sea-water in which the structures referred to had been erected, viz., whether fresh-water discharges had affected the degree of salinity, and as to the presence or otherwise of sewage, or chemical discharges, to such an extent as to influence the growth and activity of marine organisms. It was also requested that specimens of the materials with a history of the same, whether deteriorated or otherwise, should, where practicable, be furnished.

7. Information was also desired with regard to ordinary concrete, or reinforced concrete, particularly where defects had been noted due to the action of sea-water, the nature and character of such defects being communicated. Other instructions and particulars were given concerning the taking of samples, with respect to the portions of the structures from which they were to be procured, more particularly with regard to reinforced concrete, and also as to the use of mass concrete and the deleterious results, if any, arising from the action of sea-water thereon.

8. Where structures of steel and iron had been employed, it was requested that defects due to corrosion or otherwise might be noted, together with the character of such defects.

Reports received from Corresponding Members.

9. In compliance with the foregoing proposals, the Committee have received fifty-two Reports from Corresponding Members, in the sense desired, dealing with the deterioration of timber, ordinary and reinforced concrete and other materials of construction, as also with investigations bearing on the character and scope of the Research. These documents have been carefully edited and revised, as alluded to in the Introduction, and have been printed herein, either *in extenso* or in an abbreviated form.

Special articles.

10. A special article has also been prepared by Mr. Redgrave on the references to the subject of the Research, which have appeared from time to time in the Proceedings of the Institution, as far as it was considered that they afforded information with regard to the investigations connected with the Research, foot notes being given indicating where further information may be obtained if desired on the respective matters.

11. A valuable Paper has likewise been written by Mr. FitzSimons, with which are incorporated additional botanical observations and notes

contributed by Mr. F. T. Brooks, bearing specially on timber used in connection with sea structures, and containing information, which it is believed will prove useful, with regard to the conditions of growth, the dimensions of logs, means of loading for transit and other data, which should be of assistance to engineers with regard to the methods of procuring such materials.

12. Dr. Calman, Assistant in the Department of Zoology, British Museum, has also, at the request of the Committee, prepared a valuable and interesting paper on sea-organisms, with some account of their structure and life habits.

13. It is understood that a small exhibit, illustrating the natural history of marine boring animals, has been arranged in the Natural History Museum, South Kensington, by Dr. Calman. It is placed in one of the cases in the Central Hall of the Museum, and comprises specimens, models and diagrams, showing the structure, developments and habits of timber-boring Molluscs (including Teredo) and Crustacea, and of some of the principal rock-boring animals. A descriptive pamphlet is in preparation with a view to its publication by the Museum as one of its "Economic Series" of Guides.

14. Dr. J. Newton Friend has, likewise, at the request of the Committee, prepared a Paper on the corrosion of iron and steel, which Paper, it is hoped, will be supplemented hereafter by further contributions in connection with the series of experiments for which arrangements are now being perfected, and to which further allusion will be made hereafter in this Report.

15. In connection with the foregoing Papers, a large number of lithographs and photographs, received with the original communications, have been reproduced, and appear herein in connection with the letterpress of the documents to which they relate.

16. A collection of specimens of timber and other materials exposed to sea action for a number of years, has been received from Corresponding Members and others, and is now exhibited in suitable cases at the Institution, in a room set apart for the purpose. The collection already contains about 200 specimens, which it is believed will be of the utmost value for reference by engineers engaged in the design and construction of sea and river works, both at home and abroad. The labelling and cataloguing of these exhibits has been satisfactorily carried out by Mr. Redgrave. It is intended that additions shall be made to this collection from time to time, when the results of the experiments alluded to in paragraph 3 (ii), which will include testing for corrosion and durability of steel and other materials have been received, and likewise any further specimens consequent on the development of the Research. Possibly other objects of engineering interest and value may be included

Museum.

hereafter, as throwing light on the durability of sea and river structures, and of the materials with which they have been formed, the aim being ultimately to afford a valuable record, not only of the Research Proceedings, which are described in this volume, but also of the further investigations following thereon.

Synopsis of papers received from Corresponding Members.

17. Mr. M. F. G. Wilson, a member of the Committee, has very kindly prepared a valuable synopsis of the principal Papers which have been received from Corresponding Members, arranged in a convenient form for reference, and it is considered desirable that this document should appear in the Committee's Proceedings. It has accordingly been inserted immediately preceding this Report.

Destruction of timber caused by marine organisms.

18. Marine organisms such as teredo and limnoria vary in activity in different parts of the world, as also in the extent and rapidity of the damage they may cause, dependent upon the temperature and relative purity of the sea-water, the tidal range, the existence or non-existence of chemical, sewage, or other impurities present, the volume of fresh water mixed with the salt, and possibly in consequence of special local conditions. As an example, on the south and east coasts of England, Baltic timber, fairly well creosoted, may be considered to last from 15 to 20 years, whereas in the tropics, say at Colombo or Singapore, the life of such timber, similarly treated, would only be from 2 to 5 years at the utmost.

19. In former days, especially before the use of reinforced concrete in pier, jetty and wharf construction, creosoted timber was very largely employed in such works. Latterly, however, mainly owing to structures in the sea being formed to an increasing extent of reinforced concrete, the use of creosoted timber has to a considerable degree been discontinued. It is believed that but little, if any, change, either in the character of the creosote itself, or in the mode of its application to timber, with a view to render the latter more suitable for use, where exposed to attacks of marine organisms, has occurred for the last 50 years.

Possibility of improving the quality of creosote.

20. This last-named subject, as to the possibility of improving the quality of creosote and its application for the preservation of timber, has been under the consideration of the Committee for a considerable period, and much time and thought have been devoted thereto. It is proposed, in connection with its further investigation, to test samples of timber of different qualities and characteristics, impregnated with ordinary creosote as now supplied for timber preservation processes, and also with creosote containing ingredients which, in the opinion of the chemical experts who are now advising the Committee, may possibly lead to the use of improved preservatives. To this end the Committee have recently consulted Dr. Barger, F.R.S., not only with regard to the foregoing but also with respect to the making of experiments on samples of specially prepared timbers, both in this country, in the tropics and

likewise in a colder climate. These experiments are believed to be sufficiently promising with regard to prospective results fully to justify their being carried out.

21. As may have been anticipated, the opinion of the Committee points to greenheart as being the timber which is most resistant to the attacks of marine organisms, although, according to the Reports and Papers which have been submitted from Corresponding Members, there are certain other timbers which are alleged to possess protective and preservative properties; these claims have not always, however, been borne out by the results achieved in the works.

22. The timbers which apparently contain properties more adverse to the propagation and development of sea organisms than other qualities are generally of too dense and hard a description to permit of their treatment in any material degree by the injection of poisonous or other substances. It follows that the softer timbers will therefore probably prove more suitable for effective injection than those that are now considered the most durable materials for resisting the attacks of deleterious organisms.

Testing of Creosotes with the addition of poisonous ingredients.

23. In view of the foregoing it is proposed, at an early date, to continue the investigation, and also the testing of creosotes of various descriptions, and likewise of creosotes with additions thereto. Subsequently it is intended to carry out tests at Plymouth, where it is believed normal conditions, such as exist generally in this country, would prevail; at a biological laboratory which would not improbably be available; at Colombo, where tropical conditions would have to be contended with, and where teredo and limnoria have been proved to be unusually active; and at Auckland, New Zealand, where intermediate conditions might be anticipated with regard to temperature and otherwise. These observations would probably be supplemented by experiments in one of the colder ports on the Canadian coast.

Destructive action of sea-organisms in the tropics.

24. A case in point may be cited as showing the destruction brought about by sea-organisms and other causes in tropical waters, where timber structures were adopted. The wharves under the jurisdiction of the Harbour Board at a large eastern port consisted, until the year 1909, entirely of timber pile construction. They were commenced in 1865, and at the time when their demolition was determined upon in 1909 in order to clear the site for a new scheme of extensions and re-construction, they were about 9,600 feet in length, with an average width of 60 feet, and a depth of water alongside of from 18 to 40 feet at L.W.O.S.T., the tidal range at springs being 9 feet. The cost of their upkeep, due to the destructive agency of marine borers and insects, became so excessive, that it was imperative to adopt a more durable material for the construction of the new works.

25. At the port referred to, the teredo is exceedingly destructive. It attacks practically all timbers, the softer kinds being very rapidly destroyed, some of its borings are as much as $\frac{3}{4}$ inch in diameter, even in the harder woods. Piles which appear almost sound on the outside show, when cut, but little of the original solid timber section remaining.

26. No preservative composition has been tried at the port alluded to. It would not be effective in the case of the harder and more dense timbers, and its effect on the softer kinds, under existing conditions, would, it is believed, not be productive of results sufficiently durable to act as a deterrent against teredo attack. At the same port, piles have been sheathed with Muntz metal, yellow metal and zinc, but, owing to the deterioration of these materials, they have not proved very effective, and their use has long ago been abandoned. Some piles have been cased with concrete, but unless the structure in which this treatment is applied is fairly rigid, successful results have not always been achieved.

27. Reference is made in several of the Reports to the protection of timber by scupper nailing, i.e., driving flat-headed iron nails into the wood, with the heads nearly touching each other, so that the spaces between them may rust over and form a practically continuous rust-coating. Where this process is carefully carried out it adds undoubtedly to the immunity of the timber.

28. Other instances of the extreme activity of teredo in tropical waters may be given by reference to two cases in connection with the port of Colombo. When the harbour works which have been carried out there were commenced, about forty years ago, a temporary jetty was erected, to be used in connection with the landing of plant and materials for the new works. This jetty consisted of open timber piling of selected Baltic fir, creosoted with 14 lbs. of oil per cubic foot. The jetty was completely riddled by teredo in two years, and had to be replaced by a wharf of solid concrete. There, where the worm is very active, creosote as a preventative was clearly found to be of no real value, although in many of the holes, which were from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch in diameter, the smell of creosote could be distinctly detected. Under such circumstances the experience of to-day shows that there are no timbers and no preventatives which are proof against the ravages of teredo under such conditions as prevail at most tropical ports.

29. At Colombo in more recent times a cofferdam was constructed of jarrah piling,[1] in connection with the drying of an area within which a graving dock was to be constructed. About $2\frac{1}{2}$ years after the construction of this dam, the harbour or external face of the cofferdam, was so

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[1] *See* Mr. Wilson's Synopsis, page 245, as to distinguishing jarrah from karri.

severely attacked by teredo that protection had to be afforded by tipping an embankment of clay along its outer margin in order to prevent worm-action.

30. It may be observed that the teredo does not flourish in greenheart and some other timbers to the same extent with regard to development in the size of the creature itself, as in, say, untreated woods, showing that the more efficient woods contain juices, or deterrents, which retard the growth and activities of the parasites and hence increase the duration of the useful life of such timbers in sea structures.

31. The foregoing instances show the ravages of teredo under conditions which might formerly have been considered as in some measure providing for immunity from such attacks, and also indicate the necessity for special precautions being adopted in such cases where works in the tropics have to be carried out. It is hoped that the experiments, to which reference has been made, and which are about to be initiated, will lead to the introduction of some new and effective measures and preservatives which will result, at all events, in the mitigation of the enormous waste due to the destruction of timber in sea works which now occurs, and more particularly in tropical waters.

Should the Committee be successful in obtaining a mixture or combination that proves effective in warding off attacks of sea-organisms upon timber, they propose to have a number of specimens injected therewith and to forward them to the tropics for practical testing.

32. Mr. Wilson has alluded, in his synopsis, to the inconsistencies in the behaviour of timber, which constantly appear throughout the reports received from Corresponding Members. These variations are no doubt attributable to differing conditions in the growth of the timber as regards climate or soil, period and method of felling, and the considerable variations in the destructive activities of the marine organisms in different parts of the world. He points out, however, that there are certain broad general conclusions as to its behaviour which the reports would appear to justify, and in the terms of which the Committee fully concur.

33. In order to obtain further information as to the life of timber of different descriptions, the Committee have asked Corresponding Members to conduct experiments with such local woods as are used at their ports. Up to the present the Committee have been informed that such tests are being made at Auckland, Brisbane, Colombo, Halifax, Leith and Wellington. The Committee have no doubt that tests of a similar character will be carried out by Corresponding Members at additional ports, but, as previously explained, owing to the war, it has been difficult hitherto to obtain either the timber or the facilities for carrying out the work.

Corresponding Members have likewise been asked to obtain the

transverse strengths of such local timbers as are in use at their ports, by breaking small beams between points of support. It is thought that such information will be of value in fixing the physical constants now but little known of many foreign woods.

Rein-forced concrete.

34. Allusion has been made to the extent to which reinforced concrete has, in recent years, superseded timber as a material for sea and river works. No doubt this procedure will develop as time goes on, and the more so if it is found impracticable to devise some effectual method of increasing the life of structures of timber in the sea.

35. The references to reinforced concrete given in the Reports are on the whole of a satisfactory character, though, as pointed out by Mr. Wilson, many instances of deterioration are mentioned. Owing to the comparatively short period during which the use of reinforced concrete for sea works has come into operation, the conclusions to be drawn with regard to some of its characteristics cannot yet be defined with so much certainty as is desirable. As time advances the enquiries and examinations which are being made, and happily in a great many cases published, will, it is hoped, lead to the mitigation, if not to the entire removal, of such defects as exist in this comparatively new system.

36. The defects which have been observed and reported upon may be said to be almost entirely due to the corrosion of the steel reinforcements, consequent upon the penetration of moisture through the concrete covering, or coating, until it reaches the steel.

37. A full record of such defects as have been observed by the Authors of the Papers, and the conclusions arrived at by them with reference thereto, is given in the synopsis which has been referred to. Descriptions of the aggregates, proportions of cement used and recommended for adoption, the thickness of the concrete covering over the reinforcements, the special necessity for good and careful workmanship and supervision, are all enumerated, and it is believed by the Committee that satisfactory conclusions and suggestions with respect thereto are set out.

38. Experiments on blocks of reinforced concrete are being carried out by Mr. Cullen, at Brisbane, the concrete being of different strengths, and the depths of cover over the steel varying from $\frac{1}{2}$ inch to 2 inches. The results of these tests should be of value in considering the preservation of steel reinforcements and the depth of cover which is desirable.

A similar set of experiments has been made by Mr. Somers Ellis, at Hong Kong. In some of the last-named specimens the steel is coated with preservatives before being placed in the concrete, and in others the steel has had the scale chipped off and scraped clean. The depth of concrete cover varies from 1 inch to 2 inches in thickness, and the mixture from one part of cement to six of gravel and sand, to one part of cement to four of gravel and sand.

39. About 30 years since considerable discussion arose in the engineering world with respect to failures which had occurred in the use of ordinary concrete in harbour and dock works, and these failures created, at the time, a certain amount of distrust with respect to the durability of that material. After very careful consideration of the facts associated with the cases in question, and much discussion with regard thereto, it appeared to be generally agreed that the failures referred to were largely, if not entirely, due to defects in the concrete itself, and that they owed their origin to the porosity of the concrete and the infiltration of sea-water from the tideway, into and out of the same, when the material was in a "green" or unset condition. A word with regard to this important subject may not be out of place here, and it may therefore be remarked that in the case of concrete work, if the material is porous and sea-water, especially in the tideway, soaks into and subsequently exudes from it, the magnesium salts in the sea-water withdraw a portion of the lime of the cement in the form of calcium salts, and leave a deposit of magnesia in its place. It is this magnesia derived from the sea-water, alone, or mixed with lime from the cement, which constitutes the white substance deposited around the larger particles in the concrete. Generally speaking, the infiltration and exudation of sea-water consequent on tidal action, causes the chloride of magnesia in the sea-water to be decomposed, the chlorine combining with the lime of the cement, for which it possesses a greater affinity than for the magnesia, leaving the magnesia free as a hydrate, in which form it is deposited in the concrete.

Ordinary concrete.

40. Breakwaters, docks and other works, of considerable magnitude, mostly of concrete, either *en masse*, or in the form of blocks, have been constructed in different parts of the world during the last 40 years or more, without showing the slightest tendency to deterioration or failure, so that the scare to which we have referred above has now to a considerable extent, if not entirely, subsided, and it is taken by most engineers as definitely determined that properly constituted Portland cement concrete, employed as it should be, may be relied on to produce *sound and permanent* work.

41. Instances of the failure of cement concrete have come prominently before members of the Committee during their professional experience of the effect of sea-water on concrete deposited in a tideway, i.e., between high and low water, where, owing to the use of porous concrete and consequent infiltration of sea-water, results have been produced analogous to those described. Moreover in those cases where clean rubble stone has been deposited *within the concrete*, the latter being employed *en masse*, it has been possible, owing to the deposit of a white slimy substance, formed in the manner described, around the stones themselves, to withdraw such stones easily, by hand, from the

Failures noted in porous concrete work.

interior of the concrete, the work possessing, as a whole, practically no strength.

42. Generally speaking, in the construction of breakwaters or piers, where the quantity of work to be done is sufficient to justify the employment of adequate plant and appliances, the use of concrete in the form of seasoned blocks, made in a suitable yard above high-water level, and stacked for a period of, say, 2 months, before being set in position in the permanent work, in a tideway between high- and low-water level, would produce satisfactory results with greater certainty than where mass work is used in similar positions, unless the concrete is absolutely impervious to the infiltration of sea-water.

Lias lime as an ingredient for concrete.

43. During the investigations connected with this Research, reference was made to the use of lias or hydraulic lime in concrete instead of Portland cement. It is the opinion of the Committee, however, that Portland cement is in every sense a superior and more reliable material for use in concrete than hydraulic lime. Portland cement, if prepared under the British Standard Specification, is based on definite proportions and standard methods of production, which if properly applied are known to lead to satisfactory results. In the case of hydraulic lime, however, which is a natural production, formed under varying conditions, its composition must of necessity vary, and hence mortar or concrete compounded therefrom cannot be considered so reliable as would be the case if Portland cement were employed.

Roman cement.

44. With regard to the use of Roman cement in sea works, the opinion held by the Committee on this subject is entirely in favour of Portland in preference to Roman cement.

Iron and steel structures.

45. Allusion may here be made to the increased rapidity with which structures of iron, and more particularly of steel, have been found to decay in tropical waters, as compared with the life of such structures at home. It is believed by some engineers of experience that the finer the quality of the material, such as steel or the better classes of iron, the greater the rate of corrosion and deterioration. It may be observed that as a general rule "between wind and water," i.e., at and near low-water level, it is not good policy to be continually scraping and re-coating structures of iron and steel in a sea-way in the tropics. A good and natural protection for such works is afforded by the marine growths and accumulations of fish shells which gather around and adhere to the structures, thus forming a coating of lime of substantial thickness, spread over the iron or steel, and securing it, to a certain extent, from the corroding influence of the sea-water.

46. References to iron and steel structures in home waters in the Reports, received from corresponding members, are less frequent than those applicable to colonial and tropical ports. A useful general com-

parison between the behaviour of wrought iron and steel when employed in structures in temperate, as compared with tropical, climates, cannot therefore be deduced with certainty from these papers. Experiments are, however, in contemplation, which by direct tests at home and at colonial ports will, it is anticipated, hereafter afford valuable information on this subject. On the whole it would appear that corrosion is more rapid in the case of steel than in that of wrought-iron, which confirms the experience of some engineers who have had to deal extensively with open pier and jetty work under such conditions as those referred to.

47. In this last-named connection it may be observed that it has been the practice of some engineers, to protect the main piles of such structures, by providing what are known as "sleeves," or external shells encircling the piles, in the vicinity of low-water level the spaces between the insides of such sleeves and the face of the piles being filled with rich concrete, so that by the adoption of this method corrosion is cut off, to a considerable extent, from those portions which are exposed more particularly to corroding influences.

48. In the Port of London cast-iron appears to be almost unaffected in the outer Thames Estuary. In all probability this result is due to the fact that the water contains about 75 per cent. of sea-water at high tide and 50 per cent. at low tide, the remainder consisting of fresh-water discharged from inland. Where junctions with wrought-iron occur below high-water, deterioration takes place. Cast-iro

49. In connection with the Port of Dublin, Sir John Griffith has described cast iron piling, driven in the year 1847, as having been converted into graphite, though its original form was retained, except where injured by abrasion. He attributes this retention of form to the fact that the piling was always kept wet by the tide, and he contrasts this with the behaviour of cast-iron cannon ball and ball-shots which, when dredged from the sea-bed, were perfect in form, but when dried the surface burst off in layers, the whole being finally reduced to powder.

A specimen of cast iron piling, driven at the entrance to the Norwich and Lowestoft Navigation in 1832, has been submitted, which was in a good state of preservation, as far as the metal itself is concerned, but, since its delivery in London, corrosion has set in and the original outer skin is commencing to flake off.

50. At Colombo a staging of wrought-iron had been in position for about 9 years when the following conditions were observed:—Below and in the vicinity of low-water level, the rise of tide being 2 feet only, the ironwork became coated with marine growth to a considerable thickness, except in isolated spots, where the shell fish had become detached. In these last-named spots pits were formed in the surface of the iron about $1\frac{1}{4}$ inch long and $\frac{3}{8}$ inch deep, which were filled with a black powder, as

had also been observed at Penang, Kowloon and elsewhere, but this pitting had not at the time of observation taken place to a sufficient extent to affect materially the strength of the piles.

51. An interesting case which may also be cited in connection with Colombo, is that of an old *iron* rail which, during the construction of the new works, had been removed from the bed of the harbour, where it had lain, in all probability, for many years. It was then found to be considerably corroded; the fibrous parts of the metal were so reduced that the harder, or crystalline, portions projected above the surface of the softer, or fibrous, parts in the rail head to the extent of $\frac{1}{8}$ inch to $\frac{1}{4}$ inch, thus showing the more rapid wastage of the fibrous, or finer, portions of the iron, as compared with the crystalline matters.

52. Another interesting instance of the corrosion of steel piling is related by Mr. Somers Ellis in connection with open piled wharves erected at Kowloon, in Hong Kong Harbour, in 1907–9,[1] which may be perused with advantage if further information is desired on this subject.

53. The Committee have under review the preservation of steel and iron work by means of protective coatings of varying thickness and composition. It has been suggested that improvements may possibly be made by the addition of poisonous substances to such coatings. Experiments are in contemplation to determine this question.

54. Before concluding these remarks on iron and steel structures, reference may be made to the increasing difficulties and delays which have been experienced in pre-war years in procuring iron for sea structures, as compared with the supply of steel. This resulted in the use of the last-named material, in certain cases, where iron would have been preferred if that metal could have been obtained with the same readiness and facility as steel work.

Special investigations of materials in connection with contemplated tests.

55. The investigations had not long been inaugurated before it became evident that, in consequence of the war and the difficulty in procuring specimens properly prepared and treated for experimental purposes, either of timber, steel or iron, considerable delay would be inevitable in proceeding with the contemplated experiments, where the materials had to be prepared at home and issued by the Committee for testing. It was therefore decided to record the result of the proceedings of the Committee under the first head, referred to in paragraph 3 above, as soon as the investigations were sufficiently advanced to enable this to be done. Hence the issuing of this volume.

56. The Committee have arranged for experiments to be made on different qualities of steel and iron, and up-to-date samples have been procured for the purpose of testing medium carbon steel, mild steel,

[1] Minutes of Proceedings Inst.C.E., vol. cxcix., p. 133.

"Galahad" non-corrosive steel, nickel steel, Swedish charcoal iron and two qualities of cast iron.

The object of these experiments is to ascertain whether it is possible, by means of certain alloys, to produce a quality of steel, which would resist, more or less completely, the corrosive action of sea-water, and whether the use of such steels in juxtaposition with ordinary or less costly steel will be liable to give rise to electrolytic action.

57. The whole of the steel specimens have been specially manufactured for the Committee by Messrs. Hadfields, Ltd., and the remainder, consisting of wrought iron, cast iron, etc., were procured from the respective makers. Eighty bars of each description of the material, 3 inches × $\frac{1}{2}$ inch × 24 inches long, were prepared with a view to their exposure in sea-water and air in order that observations might be made as to the susceptibility of each class to corrosion.

58. Complete chemical analyses and mechanical tests of all these specimens have been made at the Hadfields' Research Laboratory, on the advice of Sir Robert Hadfield and Dr. Newton Friend.

59. It has been determined that three complete sets of the above bars shall be exposed at the selected stations, the first set to be taken up and examined after 5 years' exposure, the second after 10 years' exposure, and the third after 20 years' exposure. Should, however, experience at the time of the first examination prove that the intervals for exposure may be curtailed the specimens will be examined accordingly at shorter periods. Duration of tests.

60. As the experiments extend over such a long period, the Committee have given their serious attention to the identification of the different specimens after the exposure to which they will be subjected, and as they feel assured that any system of stamp-numbering would in all probability be obliterated, before even the first examination was made, a scheme of identification by means of perforations has been devised, which they anticipate will prove satisfactory.

The foregoing remarks may be generally summarised as follows: Summary.

1st. At the home ports, Baltic timber, which has been properly creosoted, would resist the attack of teredo or limnoria to an extent which would, it is considered, justify the adoption of such treatment.

2nd. The life of sea structures, or portions of them, in connection with home ports, would be further prolonged by the use of greenheart and to some extent by the employment of jarrah, and other Australian gums, in lieu of creosoted timber.

3rd. In tropical waters, where the teredo and limnoria are much more active than around the British coasts, the use of creosote as a protection, or preventative, would not be justified by the results produced.

4th. It is possible that, as an outcome of the experiments on improved preservatives which are in contemplation, results of a more favourable character than are now available may be obtained in connection with the treatment and use of softer woods adapted for impregnation at home and in the Colonies.

5th. Hard and dense woods are not adapted for the preservative treatment referred to above.

6th. Having regard to the foregoing, reinforced concrete is a more favourable material for use where the sea worm is very active, both at home and in the tropics, provided such a system is applied in a proper manner.

7th. In carrying out reinforced concrete structures, whether at home or in the tropics, it is of the utmost importance that a sufficient thickness of cover or coating of the steel reinforcements, say not less than 2 inches to $2\frac{1}{2}$ inches, should be provided; that the concrete should be impervious, and the materials so proportioned as to produce that result (see the Papers and synopsis published herewith).

8th. It is of special importance that careful workmanship and supervision should be employed in carrying out reinforced concrete work, and that displacement of the reinforcements should not occur during the deposit of the concrete.

9th. Ordinary concrete, whether in blocks or *en masse*, may be considered as producing thoroughly permanent work, if carried out on the lines indicated herein.

10th. The Committee defer the expression of an opinion on the relative suitability of iron or steel for use in sea structures until the experiments, for which arrangements have been made, are sufficiently advanced to enable a reliable opinion to be formed.

11th. The Committee also intend, now that facilities are available after the war, to proceed further with the investigations as to marine creatures which destroy materials used in sea structures, to which reference is made in the concluding paragraphs of Dr. Calman's Paper (p. 74) and the results of which will, it is hoped, be recorded in a subsequent volume of Proceedings.

12th. In connection with the contemplated tests of the durability of iron and steel in sea-water, and the nature and extent of the corrodibility due to exposure to sea influences, reference is made to these important questions in Dr. Friend's valuable paper, page 79. It is hoped that the experiments referred to in paragraph 46 of this Report will throw considerable additional light on the subject, especially as to the desirability, or otherwise, of the use of expensive steels in a restricted form.

13th. The Committee will be glad to receive information from time to time, accompanied by plans and photographs, and, if practicable, by

specimens for exhibition in the small museum at the Institution, from Corresponding Members of the results of further experiments they may themselves make, or which may come under their observation.

61. The thanks of the Committee are due to the Corresponding Members who have prepared and forwarded to them the Reports and illustrations printed in this volume, accompanied in many cases by plans, photographs and specimens. These communications, containing matters bearing on the Research, furnished by Engineers in charge of the respective works, are of special interest and value and will, the Committee are sure, be much appreciated by the readers of this volume. Committee's thanks to Corresponding Members.

62. The Committee are also desirous of expressing their thanks to the gentlemen who have furnished them with information with regard to timber as a material for sea works, more particularly to the Agents-General for Western Australia and Tasmania; Millar's Timber and Trading Company, who furnished valuable data as to jarrah and karri; Messrs. D. Baird & Co., who sent facts with respect to greenheart; the Siam Forest Company, for information with reference to teak; and Messrs. Burt, Boulton & Haywood, for particulars with regard to Baltic timber and pitch-pine.

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